FORECASTING WEATHER

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BY

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INTRODUCTION TO THE ORIGINAL EDITION

[The numbers of the figures and chapters referred to in this Introduction are those of the edition of 1911 and have been changed in the text of the present edition.]

In this volume I have brought to account the experience of the eleven years, during which I have been responsible for the work of forecasting at the Meteorological Office. The forecast division is one of five sections of meteorological work which is carried on by the Office. My part of the duty has been chiefly to look on while the work was done by Mr. F. Gaster, Mr. F. J. Brodie, Mr. H. Harries and Mr. R. Sargeant, the senior members of that division of the staff. Mr. R. G. K. Lempfert, who joined the Office in 1902 as my personal assistant, took his turn in the daily duty of forecasting for a year or more before he was appointed Superintendent of Statistics. He has now taken over the superintendence of the forecast division.

In 1900 I carried to the Meteorological Office an experience of twenty years' work at the Cavendish Laboratory at Cambridge. It was natural that I should watch the routine of forecasting from the point of view of experimental physics.

The progress of physical science is largely dependent upon the apparatus that is available and upon the tools which can be used. The invention of a new tool means new apparatus, and new apparatus means further progress. I have heard it said that the great progress of physical science in the 19th century was really due to the invention of the sewing machine which called into existence a number of tools designed for small but accurate work with metals. In the same way the contribution which any person can make to the progress of science depends upon the intellectual tools that he has available. My own equipment was drawn from experimental physics, and I naturally endeavoured to bring the facts of the

daily weather into relation with the physical processes which had formed the customary basis of a long experience of teaching. Such conclusions as I have been able to reach I have set down with illustrations drawn from the daily work of the Office.

It has given me the greater pleasure to try to bring the physical laboratory and the daily weather into harmony because I have found that many accomplished meteorologists live really apart from the fundamental dynamical and thermal principles which are the stock-in-trade of a teacher of physics, and, on the other hand, many accomplished students of physics are, through want of knowledge, passing by without notice the many interesting problems in dynamics and physics which the phenomena of daily weather present.

At the outset of this endeavour there is an obstacle of the most perplexing character. Some fifty years ago when Sir Henry Roscoe wrote an introductory text-book of chemistry, which gradually led to the development of chemistry as a school subject in this country, he began with a chapter on the metric system, and in my young days the metric system was in fact an essential chapter of chemistry. To the school-teaching of chemistry has been added the school-teaching of physics and the metric system remains the first chapter of physical science in every school in the country. So far as science is concerned the schools know of no masses but grammes, no lengths but centimetres, no pressures but millimetres, and no temperatures but centigrade—the metric system is part of their life. On the other hand meteorology in this country, which has never enjoyed the advantages of an elementary text-book by Sir Henry Roscoe with an introductory chapter on the metric system, still uses the inch, the grain, and the Fahrenheit degree. My illustrations are necessarily drawn chiefly from weather charts which use these units exclusively. To understand a weather chart, some instruction is required for which we might reasonably appeal to the science masters in the schools. But, if we do, they will

expound in the metric system the principles for which illustrations will be given in British units on the map.

Like every other writer on meteorology in this country, I am upon the horns of a dilemma. If I talk about my maps in the language of the schools, the figures will not tally and the meteorologists will protest. If I talk about them in the language of the maps, the schools whose interest I should like to enlist will be scandalised in the scriptural sense.

In dealing with the physical explanations the dilemma is a very serious one. I know of no one who is operatively conversant with the thermodynamics of moist air as found in the atmosphere in terms of grains, inches, and Fahrenheit degrees. If any one wishes to find the latest information in the way of tables, formulæ or calculations he must be familiar with metric units. It is obvious that for either class of readers a preliminary chapter on units is inevitable.

I have had great difficulty in deciding how to meet this dilemma in dealing with the physical considerations. So far as pressure is concerned I have endeavoured to use the "atmosphere," which is common ground, but I have used the centimetre-gramme-second atmosphere (75 cm., or about 29·5 inches of mercury) for reasons which are set out in various publications.

For temperature, in dealing with humidity, I have used the Kelvin or absolute scale, *i.e.* the scale of centigrade degrees measured from 273° below the freezing point of water.[1] The standard boiling-point of water on this scale is 373°A. The use of the C. G. S. atmosphere of 1,000,000 dynes per square centimetre and the expression of temperature in Centigrade degrees from absolute zero was introduced into the Weekly Weather Report for 1909 and has the approval of the Gassiot Committee of the Royal Society.

I add a word about this scale of temperature. Its primary advantage is that it gets rid of all negative values from atmospheric temperatures, and simplifies the expression of the laws of gases, of radiation, and of thermodynamics. It has been

[1] See Introduction to Second Edition, p. xxi.

objected that 0° C., the freezing-point of water, is such a cardinal point in practice, since it corresponds with the transformation of water into ice, or ice into water, that it ought to be retained at all costs as the zero of the temperature scale. I should like to urge that the facts in connection with freezing furnish the strongest argument for an alteration of the practice. The use of zero for the freezing-point misleads people into thinking that it is a critical temperature in practice, that anything made of water is fluid above 0° and solid below that temperature. It is not really so. The centigrade zero is the freezing-point of water in the laboratory under carefully organised conditions; it is not the freezing-point of the water that covers four-fifths of the globe, or of that in the harbours that are periodically blocked with ice. It is not the freezing-point of the water contained in the cells of plants; that is probably different in different plants; in "tradescantia" stamens it is − 6·5° C.

It is not the freezing-point of the water carried as droplets in the atmosphere—that is probably different according to the size of the drops. That clouds are not always ice below 0° C. is evident enough on any day when it "freezes" in this country. There is a physical distinction between water-drop clouds and ice-particle clouds which is shown by the formation of halos. And clouds which, so far as can be judged from their optical properties, are water-clouds, can be observed in conditions when the temperature of the atmosphere is below 0° C. The implied suggestion that 0° C. is a critical temperature which divides water from ice has the effect of screening off the subject from the investigation which is necessary for ascertaining the real facts. It is therefore a hindrance and not a help to progress, and the assignment of a figure for the freezing-point which has not the air of finality about it presented by the rounded zero is in itself no small advantage. Any application to the atmosphere of thermodynamics which assumes that waterstuff below 0° C. is ice must necessarily lead the investigator into error.

It is truly the temperature at which snow and ice thaw on the ground and it is therefore a critical temperature with reference to the *débâcle* of rivers, but it is not necessary to fill our tables with positive and negative signs lest we should forget that the ice will begin to melt above 273° A.

This, however, is not the chapter on units which I have said is inevitable, it only shows some of the reasons why such a chapter is wanted. I have postponed the matter too long now to make a chapter generally applicable in this work but I give here a skeleton which I hope may sometime form the basis of an effective chapter on units. It must start from a point beyond that from which Sir Henry Roscoe started, because the expression of ideas connected with force, gravity and thermodynamics brings us into the region of absolute units, and for absolute units the C. G. S. system is now used universally both for electrical and also for magnetic measurements, and has therefore found a home in close association with the meteorological observatory. My skeleton chapter will therefore carry the C. G. S. system in its heading.

THE C. G. S. SYSTEM OF METEOROLOGICAL UNITS

The C. G. S. system of units now used universally for electrical and magnetic measurements is based upon the metric system. The initials stand for centimetre, gramme and second.

In the metric system the multiplication of the unit by 10, 100, 1,000 1,000,000 is indicated by the prefixes deka, hecto, kilo, mega, and the 10th, 100th, 1,000th, 1,000,000th part is indicated by the prefixes deci, centi, milli and micro.

The *centimetre is one-hundredth of a metre, the unit of* length from which the name of the metric system is derived.

The gramme is the metric unit of mass, and was originally intended to be the mass of a cubic centimetre of water at the freezing point. It approximates to that specification very

closely. It is the thousandth part of the standard "kilogramme" of the International Bureau of Weights and Measures.

The second is a universal unit of time. There are 86,400 seconds ($60 \times 60 \times 24$) in the mean solar day by which all "mean time" clocks are set and rated.

The unit of area in the C. G. S. system is the square centimetre. the unit of volume is the cubic centimetre.

The density of a substance in the C. G. S. system is the mass in grammes of a cubic centimetre of the substance. In the C. G. S. system the density of a substance is numerically the same as the specific gravity of the substance.

The unit of velocity in the C. G. S. system is the velocity of a centimetre per second.

The unit of acceleration in the C. G. S. system is the acceleration of 1 unit of velocity per second, or 1 centimetre per second per second.

The unit of force in the C. G. S. system is the force which produces an acceleration of 1 centimetre per second per second in a mass of 1 gramme. It is called a dyne.

The numerical expression of the force acting upon any mass in the C. G. S. system is the product of the number of grammes which it "weighs" and the number expressing the acceleration which the force produces if allowed to act undisturbed by other forces.

At sea level in latitude $49\frac{1}{2}°$ the acceleration of gravity upon any falling body is 981 centimetres per second per second, hence the force of gravity upon the mass of a gramme is 981 dynes. This is the weight of a gramme. The reader will notice a curious confusion here; one uses a balance to "weigh" a body, in reality to find its mass. The operation is only a part of the finding of its weight.

The unit of pressure in the C. G. S. system is a dyne per square centimetre.

For practical electrical and magnetic measurements certain multiples or sub-multiples of the fundamental C. G. S. units

are adopted, and, following the same lines with a view to practical meteorological measurements, we arrive at the following:

The accepted normal pressure of the atmosphere, or "standard atmosphere," is that of a column of mercury 76 centimetres high at the freezing-point of water under the conditions as to gravitation which are to be found in latitude 45° N. or S.; for other latitudes a small correction is necessary to allow for the difference of gravity. This pressure of a standard atmosphere is 1,013,193 dynes per square centimetre, or approximately 1·013 megadynes per square centimetre.

The practical unit of atmospheric pressure in the C. G. S. system is the megadyne per square centimetre, which may be called the "C. G. S. atmosphere." It is referred to in this book as an "atmosphere." It is equivalent to a pressure of 750·1 millimetres of mercury at the freezing-point of water in latitude 45° and is the normal air pressure at 106 metres above sea level. The name of "bar" or "barye" was agreed upon for this unit at the Conference of Physicists in Paris in 1900.

The practical unit of wind velocity is the metre per second, 100 times the C. G. S. unit of velocity.

The practical unit of rainfall measurement is the millimetre of rain, one-tenth of the C. G. S. unit.

There is no practical unit in the C. G. S. system in use for wind force on an exposed surface, a great variety of units are used in practice. The thousandth part of an atmosphere, the millibar, *i.e.*, 1,000 dynes per square centimetre, would be a suitable unit, but no special name has yet been assigned to it. The absolute unit of pressure, the dyne per square centimetre, is used here.

The practical measure of temperature is so chosen that the volume of a mass of gas at constant pressure, or the pressure of a mass of gas at constant volume, is proportional to the temperature. It is the temperature on the centigrade scale increased by 273.

The British equivalents of these units are as follows: —

length	1 centimetre	= ·0328 ft.	= ·394 in.
mass	1 gramme	= ·00220 lb.	= 15·4 grs.
time	1 second	= 1 second.	
area	1 square centimetre	= ·00108 sq. ft.	= ·155 sq. in.
volume	1 cubic centimetre	= ·000035 c. ft.	= ·061 c. in.
velocity	1 centimetre per second	= ·0328 ft. per sec.	
		= ·0224 miles per hour.	
acceleration	1 centimetre per sec. per sec.	= ·0328 ft. per sec. per sec.	
force	1 dyne	= ·0000722 poundal.	
pressure	1 barye or megadyne per sq. cm.	= 67390 poundals per sq. ft.	
temperature	1 degree A.	$= \frac{9}{5}$ F°	

Some of the more frequently occurring formulæ are as follows:—

1. Density (ρ), volume (v), mass (m).

$$m = v\rho$$

2. Force (f), mass and acceleration (a).

$$f = m \times a$$

3. Weight (w), mass and acceleration of gravity (g).

$$w = m \times g$$

4. Anemometrical formulæ:

Wind force in dynes/sq. cm. (P) and velocity v in metres/sec.

$$P = 7{\cdot}2\, v^2 \text{ dynes per sq. cm.}$$

Wind force in dynes/sq. cm. and Beaufort number, (B).

$$P = 5\, B^3 \text{ dynes per sq. cm.}$$

Wind velocity in metres/sec. (V) and Beaufort number.

$$V = {\cdot}83\, B^{\frac{3}{2}}.$$

5. Gaseous laws of relation between pressure (p), temperature (t) and volume (v).

$$\frac{pv}{t} = \frac{p_0 v_0}{t_0}.$$

6. Pressure and temperature under adiabatic conditions (dry air).

$$(\gamma - 1)(\log p - \log p_0) = \gamma (\log t - \log t_0).$$

PLAN OF THE BOOK

The arrangement which has been followed in this work is first to explain and illustrate the construction and use of synoptic charts and the method of forecasting by their means. In this section I have quoted the empirical rules which have been framed in the light of long experience as set out by the late Hon. R. Abercromby. In passing I have dealt with the relation of wind velocity to the distribution of pressure, a subject which is becoming daily of greater importance for us.

After setting out the position arrived at by empirical generalisation I have turned to an examination of the physical processes which are involved in the phenomena of weather and have given illustrations of the connection between the observed phenomena and the processes upon which in some form or other they must depend.

In the subsequent chapters of the book I have dealt with special departments of the work of forecasting, such as gales and storm-warnings, anticyclonic weather, land and sea fogs, night frosts, colliery warnings, forecasts for aeronauts.

These are followed by a consideration of recent developments of the practice of forecasting by the use of weather charts as exhibited by the work of Ekholm upon isallobaric charts and that of Guilbert on the approach of depressions and local deviations from the "normal" wind. A chapter has been devoted to statistical methods for long-period and seasonal forecasts. The book concludes with what I hope is an impartial appreciation of the utility of the system of weather forecasts in this country.

ACKNOWLEDGMENTS

For the illustrations I have relied mainly upon the maps of the Daily Weather Report of the Meteorological Office. In order, however, to include information as to temperature as

well as pressure upon a single chart the maps have been redrawn by Miss E. Humphreys, a member of the Office staff, who has prepared the original drawings of many other of the illustrations. Blocks for Figs. 60—70 have been lent by the Meteorological Committee. The frontispiece and Figs. 3—5, 42—48, 50, 53, 54, 57, 58, 81, 83—86, 89—91, 97—104, 113—114, 127—129, 135—141, 146—148, 155, 156, are taken from the Reports or publications of the Meteorological Office and are reproduced by permission of the Controller of H. M. Stationery Office.

Other illustrations are taken, directly or indirectly, from the official publications of other countries. I have endeavoured to give references to the sources of the illustrations for which the Meteorological Office is not ultimately responsible. A considerable number of drawings (Figs. 7—12, 79, 80, 82, 121) are reproduced from blocks lent by the Royal Meteorological Society, and the paper from the Journal of the Society, which is included in Chapter VI., is reprinted with the sanction of the Society.

To many fellow-workers, therefore, in a common task, I take this opportunity of expressing my grateful thanks, not least to my colleagues on the Meteorological Committee, for the encouragement and assistance which they have given me in carrying out a work which has no definite place among the manifold duties of the direction of the Office. Three other cogent reasons account for the appearance of this work at a time when changes in the Office have made administration unusually onerous. First, the reiterated requests of Messrs. Constable & Co. for a restatement of the position of the work of forecasting weather, taking account of modern developments: to them I am greatly indebted for the unfailing courtesy with which they have met the many and difficult requirements of a procrastinating author; secondly, the necessity for dealing with the subject in its turn as a part of meteorology within the scope of the duty of the reader in that subject in the University of London; and thirdly, the

demand of my colleagues on the Advisory Committee for Aeronautics for a report as to the formation of cloud, snow, etc., for the use of persons interested in the navigation of the air.

I feel bound to point out that procrastination has disadvantages. The manuscript of this work was completed and dated August 11, 1910. It included as Fig. 3 a copy of the Daily Weather Report of the Meteorological Office for reproduction in reduced *facsimile* in order to represent the latest development of that publication. The *facsimile* appears in the book entirely *comme il faut:* but it no longer represents the "Daily Weather Report." Somewhat unexpectedly the removal of the work of the Office from Victoria Street to South Kensington was followed by the installation of a lithographic press on the premises: therewith a change of printer, and, in consequence, new outlines for the charts and other changes dating from January 1, 1911, embodying the improvements which the writing of this book had itself suggested. I have hesitated for some time as to whether I should let the *facsimile* stand or ask that it should be replaced by one representing, as I think, a much improved daily report. For two reasons I have decided to allow it to stand: first, because the report which is reproduced is the first containing a "further outlook," and marks a departure of greater meteorological significance than the changes, chiefly administrative or geographical, of last New Year's Day; and, secondly, because any further changes, even if they are improvements, will carry me safely beyond the termination of the administrative year of the Advisory Committee for Aeronautics, and with a new administrative year a new period of procrastination would probably supervene.

The book is mainly dependent upon its numerous illustrations, of which many have been reduced from original charts of a larger scale. It is to be feared that the details of the charts have in some cases suffered in the process, and are represented on so small a scale that a magnifying glass is

wanted to make them out. There is, however, no alternative except reproduction at full size, which would have made the book too cumbersome.

To the acknowledgments already made I have to add my thanks to Mr. R. Corless, of the Meteorological Office, and Mr. J. S. Dines, Meteorologist for the branch of the Office at Farnborough, for assistance in reading the proofs and verifying the numerical assertions and preparing the index; and also to Miss H. M. Shingleton for seeing corrections through the press.

W. N. Shaw.

Meteorological Office,
South Kensington, S.W.,
July 17, 1911.

INTRODUCTION TO THE SECOND EDITION

In 1911 when the first edition of this book was published, we were feeling our way towards the observational study of the upper air as an essential step in the comprehension of the atmospheric processes which are expressed by our weather. As a natural consequence of dealing with a much wider range of observation of all the meteorological elements than is required for the weather at the surface, we had also begun to feel our way towards the universal expression of meteorological measurements in units belonging to the centimetre-gramme-second system which has proved so effective in the case of electrical and magnetic measurements, and was, in fact, employed as a matter of course for electrical and magnetic measurements at the principal observatories of the Meteorological Office.

The happenings of the past twelve years, which include the unparalleled circumstances of the Great War from August 4, 1914, to November 11, 1918, have had their influence upon both of these aspects of meteorological work.

EXTENDED METEOROLOGICAL OBSERVATIONS AND REPORTS

The few aeroplanes and airships which represented the national equipment of the Air Services of 1911 became multiplied into thousands of aeroplanes and a complete patrol of the British coasts by airships: innumerable kite-balloons with standard winches and other gear for manœuvring them, were at the service of those who wished to explore the upper air; anti-aircraft guns, *à discrétion*, to produce smoke-puffs at any desired height (within limits), and reticuled mirrors on which to trace their tracks and

thence obtain the horizontal and vertical velocity of the current in which they drifted, came into regular use. The pioneer establishments for meteorological observation in charge of trained meteorologists at South Farnborough, Upavon and Kingsnorth, in connexion with the Air Services before the war, became reduplicated as fully equipped meteorological stations in the home country and on the various battle fronts with sections of the Royal Engineers and of the Royal Naval Air Service specially devoted to meteorology. Observations of pilot-balloons became an indispensable requisite.

The immense development of meteorological activity which came with the war expressed itself mainly in the vastly increased amount of information which was demanded from the meteorological services by the naval and military authorities, and the much more elaborate detail of information which was required, particularly for questions concerning gas-warfare, sound-ranging and other departments of gunnery. The information about the atmosphere which was contributed in return by the airmen who crossed the sky daily in flights and squadrons was extraordinarily small—only some occasional observations of temperature—until towards the end of the war some excellent photographs of clouds taken from above were made officially; observations of temperature became more or less regular, and the kite-balloon began to emerge as an effective method of observing, with self-recording gear specially designed for use therewith.

None of the new methods of observing had, however, become so much regularised as to survive the end of the war. An enormous number of records of observations of pilot-balloons are available as part of the heritage of the war's activity. Their ultimate value in forecasting has yet to be explored and explained. The outstanding feature, however, of the twelve years' experience is a greatly increased demand on the part of the Air Services of this and other countries for more and more detailed observations. The tendency is expressed in this edition by the increase of size of the facsimile of the Daily Weather Report from four to ten pages and the corresponding increase in the number and com-

plexity of the codes for the transmission of messages. These are set out as an addition to Chapter I.

A new field of observation is opened up by the necessity for specifying and forecasting the transparency of the air for the service of aerial navigation. Endeavour is made to satisfy the requirements by noting the distance of visibility with the aid of a series of landmarks at successive distances. The endeavour provokes inquiry into the physical conditions of good visibility and bad visibility. It is a difficult question because visibility may be impaired by water-drops, or by dust without water-drops, and the association of water-drops with dust or other nuclei for condensation is not yet fully explored. Moreover, the effect of any form of cloudiness upon the visibility of a distant object is affected by the way in which the intervening cloud is illuminated, as well as by the illumination of the object looked for. A chapter is accordingly devoted to some of the physical aspects of visibility and their relation to typical meteorological conditions.

THE USE OF C.G.S. UNITS IN METEOROLOGY

Very little that is different can be said of the effect of the twelve years upon the progress towards the universal use of C.G.S. units. The lines along which progress seemed to be natural are set out in the Introduction to the First Edition. What was there indicated as probable and tentative became definite and actual. C.G.S. units came into use in 1911 for meteorological elements in those observatories which already used them for electrical and magnetic elements, and the twelfth year of publication on those lines is now in progress. We chose units based on centimetres and grammes for use in meteorology principally because those are the units which are universally employed in the physical laboratories where the essential properties of the atmosphere must be learned. It is astonishing how exclusively the gramme is employed in such institutions. For twenty years, up to 1900, I was employed in teaching physics at one of the chief physical laboratories of this country, and I never once saw a weighing executed in grains—always grammes were used. And the

Fahrenheit thermometer was only used for exercises in comparison: measurements of temperature were always in the centigrade scale for the very good reason that all the tables of reference for physical constants were given in that scale.

So pressure, tentatively represented in this book as a fraction of an "atmosphere" in the Introduction, and in Chapter VIII. as thousandths of a C.G.S. atmosphere in Figs. 146A. and B. of Chapter XI., and expressed in the unit of pressure of 1,000,000 dynes per square centimetre in Chapter XXI., soon fell into line with the practice of Professor V. Bjerknes and his colleagues in their work of "Dynamic Meteorology and Hydrography," published by the Carnegie Institution of Washington in 1910 and 1911; the millibar, as representing 1,000 dynes per square centimetre, became the accepted unit of pressure for our own charts, for charts of the Northern Hemisphere, published by the United States Weather Bureau, and subsequently for the daily charts of the Bureau Central Météorologique of France. When challenged at an International Conference of Directors of Meteorological Institutes and Observatories at Paris in October, 1919, it was approved by the Conference as the most suitable unit for the international requirements of aviation.

Hence the millibar of 1,000 dynes per square centimetre will probably in time be universally accepted as the unit for pressure. Its employment in this country has already exhibited in a useful light the possible simplification of the method of dealing with observations of the mercury barometer when the object of measurement is recognised as pressure, and not the length of a column of mercury under certain arbitrary conditions.

Some difficulty still exists about the name. Professor McAdie, of Blue Hill Observatory, would lay an embargo upon the use of the word *millibar* for 1,000 dynes per square centimetre because it implies that the "bar" is 1,000,000 dynes per square centimetre and some distinguished chemists had used the word *bar* to mean the dyne per square centimetre before Professor Bjerknes claimed its use for the C.G.S. atmosphere of a megadyne per square centimetre. He would substitute the word *kilobar* for *millibar*;

but such a word conceals the important fact which *millibar* carries on its face, that the unit is approximately one-thousandth part of the normal pressure of the atmosphere. It is not quite certain that in 1910 the word *bar*, as the initial syllable of the words *barometer* and *barograph*, was really at the disposal of any one who chose to assign a meaning to it. It has at least inherent implications if not meanings. A barometer is an instrument for measuring the pressure of the atmosphere, not for demonstrating the C.G.S. unit of pressure.

The difficulty will have to be solved by some artifice which will commend itself by its simplicity, and in the meantime no serious confusion is likely to arise.

The scheme of units which was adopted for the observatories in connexion with the Meteorological Office included the expression of temperature on the centigrade scale measured from a zero 273° below the freezing point of water because so many physical relations depend upon that measurement either as expressing the laws of expansion of gases, or as dependent upon the temperature on the absolute thermodynamic scale expounded by Lord Kelvin, and often called by his name.

For the purpose of meteorology the numerical difference between the scale used and the absolute thermodynamic scale is of no importance; but Professor Marvin, Chief of the United States Weather Bureau, rightly called attention to the fact that the scale of centigrade degrees measured from −273° C. is not, in fact, the same thing as the absolute scale and that another name is required. We have accordingly used the expression *tercentesimal scale* to indicate the arbitrary scale so defined. The adjective is long and perhaps not very euphonious; but it has one great advantage: it cannot easily be misunderstood. In this book I have used the symbol t for the temperature on the tercentesimal scale. It may be objected that elsewhere I have used the symbol a or A. That is, indeed, true: the use dates from a time when they might stand for absolute, and now, as they must not do that, when the absolute scale is not really intended, meticulous accuracy demands the use of another symbol.

The great practical advantage of the use of the tercentesimal scale in meteorology as expanded by the extension of observations to the highest reaches of the upper air is that negative values of temperature are avoided. So soon as one begins to consider the physical meaning of temperature, negative temperature must become a mere convention and a serious obstacle to any understanding; and especially to organised teaching of the subject on a physical basis. With a little practice we get accustomed to temperatures round about 200 t. from 220 t to 180 t, as representing the temperatures of the stratosphere, and 200 t becomes a sort of subsidiary datum-point for the purpose of reference. Yet, strange as it may seem, there are people, and apparently people of commanding influence, who find it easy to understand a temperature of $-31°$ F. while 238 t conveys no meaning to them. So the decision which was taken in 1911 to express temperatures of the upper air in the absolute or, more strictly, the tercentesimal scale, has not held. It has, however, established itself in the attached thermometers of mercury barometers, and there it is peculiarly useful because it helps to avoid confusion between readings of the temperature of the mercury of the barometer and the temperature of the air.

While we are dealing with nomenclature it may be well to refer to a practice which grew up at the Meteorological Office in the course of the preparation of the "Meteorological Glossary" in 1916, of using the expression "lapse rate" of temperature for the rate of change of temperature with height. The reason for the practice was that we found ourselves frequently using gradient of temperature for the change along the horizontal which is in accord with practice as regards pressure: so to avoid confusion a new name was necessary for the change in the vertical.

PROGRESS IN THE THEORY AND PRACTICE OF FORECASTING

While these things have been developing, or failing to develop, in consequence of the war, as the case may be, as in 1911 they were expected to do, there has been great activity in the theory and

practice of forecasting to which reference must be made in reviewing the present position of the subject. We have, for example, now an exposition of the practice of forecasting in the United States by a Board composed of Alfred J. Henry (Chairman), Edward H. Bowie, Henry J. Cox, and Harry C. Frankenfield, which was initiated by Professor Marvin in November, 1913, and was published in Washington in 1916. It deals with the behaviour of cyclones in relation to the attendant anticyclones much more in detail than we are accustomed to in this country. Our cyclones are hardly with us long enough to develop real personal acquaintance.

The chief event in the department of forecasting weather is the introduction by the Meteorological Institute of Bergen of a new analysis of the weather of a cyclone with reference to two lines which meet at the centre, and are called the warm front and the cold front respectively. This new analysis has been worked out by J. Bjerknes, H. Solberg and T. Bergeron on the basis of an idea of a surface of discontinuity between polar and equatorial air which has formed the fundamental conception of a theory of the atmospheric circulation by Professor V. Bjerknes. The new analysis adds precision to our ideas of the distribution of rainfall, and its introduction has been called "epoch making." Some account of it will be found in Chapters V. and X.

In France attention has been given to the idea of co-ordinating the features of weather according to the pressure-differences for a fixed interval of time. Isallobars are drawn after the manner of Ekholm as indicated in Chapter XXII., and they receive the name of *noyaux de baisse*. The shape, distribution and sequence of clouds has also received very special attention as a means of forecasting. These are specially interesting because the problem which presents itself in France is generally the problem of the southern margin of a cyclone on its westward way.

In this country Colonel E. Gold has provided a ready means of reference to types of barometric distribution, by which the current situation can be handled more definitely than by the unaided memory of the forecaster. In Australia Mr. Quayle has traced

the influence of the northerly winds upon the rainfall of the southern parts of the country, and in the Argentine Mr. Clayton has essayed the variation of the solar activity as a means of forecasting changes of temperature.

The re-establishment of the collection of meteorological information from ships at sea by radiotelegraphy, and new arrangements for broadcasting weather reports have provided ships at sea with the facilities for the construction of synoptic charts. A recent number of the "Chart of the North Atlantic Ocean," No. 255, for June, 1922, explains the codes and substances of meteorological messages broadcasted by countries bordering on the North and South Atlantic, viz., Great Britain (Clifden), France (Eiffel Tower), Holland (Scheveningen), North Africa (Tunis), Canada and Newfoundland (Barrington Passage, Cape Sable, Cape Race, Belle Isle, Fame Point, St. John's), Bermuda (Somerset Island), Jamaica (Christiania), United States (Arlington, Key West, Point Isabel, San Juan P.R., Portland, Boston, New York, Philadelphia, Baltimore, Norfolk, Charleston, Savannah, St. Augustine, Miami, St. Petersburg, Pensacola, New Orleans, Galveston), Mexico (Campeche, Payo Obispo, Vera Cruz, Salina Cruz), Panama (Balboa), South Africa (Cape Town), Brazil (Ilha do Governador), Uruguay (Cerrito), Azores (Faleiras, Monsanto).

In addition to the regular weather messages, warnings of gales, storms or hurricanes are sent from many stations. A book of instructions in the art of constructing and using such charts has been prepared by Commander L. A. Brooke Smith, Superintendent of the Marine Division of the Office, and issued as an official publication, M.O. 216.

SUMMER TIME

Among the innovations incidental to the war one of the most striking is the adoption by Act of Parliament of what is known as summer time. From the time of the adoption of a common standard time for the whole country, up to 1916 Western European time, that is civil mean time of the meridian of Greenwich, was the standard time for all civil purposes for the United Kingdom. The clocks of Middle Europe one hour in

advance of ours kept the time of the meridian of 15° E. By the Acts imposing summer time all clocks in the kingdom were advanced one hour. Middle European time became the standard time of this country for periods fixed by some competent authority. During those periods all undertakings and obligations in which time is specified are interpreted in accordance with the clock as adjusted and not with Greenwich mean time.

The periods during which these adjustments have been in operation are—

1916, May 21—Oct. 1.	1920, Mar. 28—Oct. 25.
1917, April 8—Sept. 17.	1921, April 3—Oct. 3.
1918, Mar. 24—Sept. 30.	1922, Mar. 26—Oct. 8.
1919, Mar. 30—Sept. 29.	1923, April 22—Sept. 16.

The effect of this innovation upon meteorological operations is for the most part indirect. Climatological observers adhere to local mean time and synchronous observers to Greenwich time. During summer time all their observations are in consequence nominally one hour in arrear. A certain amount of inconvenience may be felt. Post Office facilities available up to six o'clock in winter are shut off at five o'clock (G.M.T.) in summer; and no public clamour has been excited by the loss of these facilities. But this is not the place to ponder the conclusions which ought to be drawn from that fact. The warning to avoid confusion which is to be found in the Daily Weather Report survives in Fig. 46.

ACKNOWLEDGMENTS

These various subjects all belong in a general way to the science and art of forecasting weather, but cannot all be adequately treated in this book. For the information which is included for the first time in this edition, I owe the following acknowledgments:—

To the Controller of H.M. Stationery Office for permission to reproduce Figs. 1—6, 25, 36, 46, 48, 49, 59, 71, 72, 129, 157, 160, 166, 167, 180, 188. Many of the new illustrations were

prepared for me by Miss E. V. Turney, of the Meteorological Office staff;

To Mr. G. A. Clarke for the collective photographs which are comprised in Figs. 7 and 8, and which he made from prints of his own negatives or from those of the authorities named on the plates;

To the Royal Meteorological Society for permission to reproduce Fig. 127 and for the loan of the block of Fig. 174, and to Mr. G. I. Taylor for permission to reproduce the latter figure. The Cambridge University Press has provided the groundwork of Fig. 11.

For this edition Miss E. E. Austin has rendered the same efficient assistance which for the older edition I owed to Mr Lempfert and Mr. Corless.

For the reading of the proofs we are jointly indebted to Commander L. G. Garbett, R.N., Superintendent of Navy Services at the Meteorological Office: to Mr. A. W. Lee, M.Sc., of the Physical Laboratory of the Royal College of Science; and to Mr. E. G. Bilham, A.R.C.Sc., Assistant Superintendent in the Forecast Division of the Meteorological Office.

I cannot conclude this Introduction without a note of recognition for the skill and patience which Messrs. Constable have shown in the difficult task of getting into reasonable shape a work which presents so many awkward difficulties as this, or any other work on the dynamical and physical properties of the atmosphere, that depends very largely upon illustration by charts and diagrams.

NAPIER SHAW.

APRIL 20, 1923.

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FORECASTING WEATHER

CHAPTER I

SYNOPTIC CHARTS

THE practice of forecasting weather, now sixty years old, depends mainly upon conclusions derived empirically from the study of synoptic weather charts. Its rules are partly formulated and partly exercised by the subconscious induction of prolonged experience. In the course of the forecast work at the Meteorological Office ten years ago more than eleven hundred original maps were prepared each year, and more than three thousand manuscript copies made. The number of charts made and of the data charted is now very much greater: the making and reading of synoptic charts form an almost continuous process. It becomes difficult to realise that the art of reading a weather map is one that requires any introduction or explanation even for the general reader. Some preliminary explanation may, however, find a place here.

By a synoptic chart we may understand a map of the geographical region under consideration showing the distribution of the various meteorological elements over the region for the same point of time, or for the same interval of time. We may use a synoptic chart to show the distribution of mean pressure for a month by entering upon the map the average of daily readings of the barometer, properly corrected, upon a uniform plan, for temperature etc., at a number of observing stations within the region. Or we may write down upon the map the individual readings of pressure at the various stations, duly corrected as before, at the same hour of observation. The other meteorological elements may be dealt with in similar manner. Charts,

which represent the distributions at the same epoch, or point of time, are called *synchronous charts*, and it is these which are used in forecasting; but they are frequently referred to simply as synoptic charts without any indication that, as regards the chief meteorological elements, the distribution for a specific epoch is represented. Various devices are adopted in order to use a single map to show at one view the distribution of a number of elements over the region—for example, wind-direction may be shown by the direction in which an arrow points, wind-force by the particular kind of arrow or by the number of its feathers; lines, full or dotted, may show the distribution of one or more elements, such as pressure and temperature, and letters, figures, or symbols the local values of others.

The distribution of the elements will, of course, be the same whatever units are chosen for their measurement, but the actual lines selected for the representation will be different because the lines are drawn for round numbers. A great change therefore came over the mapping for the Daily Weather Report when the Meteorological Office decided to publish pressures in C.G.S. units, centibars or millibars, rainfall in millimetres and winds in metres per second. That step was taken in 1914 and the change took effect in the issues of the Daily Weather Report on May 1 of that year. In the Weekly Report the change had already been introduced on the first day of the year. Temperatures were still expressed in Fahrenheit degrees, although the tercentesimal scale[1] had been introduced for the attached thermometers of ships' barometers. The Weather Bureau of the United States accepted more completely the logic of the situation and published daily maps of the Northern Hemisphere in millibars and tercentesimal temperatures. A similar practice was followed with the daily charts of the Atlantic Ocean and adjoining continents, which at that time formed a notable feature of the Weekly Weather Report; pressures were given in centibars, temperatures of the air in the tercentesimal scale.

[1] See Introduction to the Second Edition, p. xxi.

Thus the year 1914 marked an important epoch in the history of synoptic charts. The changes were overshadowed by the war, and when the war was over the situation proved to have been confused by yielding to the idea that new readers of an old subject will find it easier to understand the modern developments if old units are utilised. The change from Fahrenheit to tercentesimal might have been carried out in 1914 with little delay; in 1921 it seemed further off than it did seven years before. But many other changes have been made which are even more drastic. Observations were made four times a day, at 01 h., 07 h., 13 h., 18 h., adopting the prevailing military notation. The weather, and cloud at the time of observation, which had to be classified into ten types in 1914, emerged from the war with two hundred types, one hundred for current weather and another hundred for past weather. A numerical scale for visibility and another for fog had been introduced, and observers were taught to define visibility by noting the most distant among a series of objects, previously selected for the purpose, which could be seen from the point of observation. Observations of winds at various levels made by means of pilot-balloons had become available from many aerodromes where professional meteorologists were stationed, and a few observations of temperature in the upper air from aeroplanes; observations of cloud had been reorganised into "high" cloud and "low" cloud, and many details of extent and height were given. In 1919 the Daily Weather Report was extended from four quarto pages to ten such pages, four being devoted to British observations and their representation on a map to the scale of 1 : 10,000,000, aided by some observations from the neighbouring continent and islands; four others are devoted to an International Section which displays, on one broadside, maps for 07 h. and 18 h. of the previous evening on the scale of the old map of 1914, viz.. $1 : 2 \times 10^7$ with inset maps of 01 h. and 13 h., and, on the other, observations at the various stations on the Continent and Atlantic Islands, from which, together with the British observations aforesaid, the maps have been compiled. Another section of two pages was devoted to observations of the upper air.

A new feature was introduced in the form of records of sea and air temperatures in mid-channel, which by the favour of the ships' owners and officers, came from the vessels on the cross-channel passages between Great Britain and Ireland or the Continent. More recently the effort seems to have languished, but something still survives, and some day we may learn from the observations something about the conditions for sea fogs.

Within the last few months reports by radio-telegraphy from the ships on the Atlantic have appeared again in the reports and with much more elaborate observations than were obtained between 1907 and 1914.

Thus the new Daily Weather Report, with its ten quarto pages, represents more far-reaching changes than all those which intervened between the first lithographic reproductions of the report and the issues of 1914. It is not possible to combine the two types in one description, and therefore we will retain the facsimile reproduction of the report for April 1, 1910, and the description which is applicable thereto and to the issues in the thirty years which have preceded it, and we will add a new facsimile for October 1. 1921, and a new description of the compilation, which includes about 2,500 separate facts each day about British weather, and perhaps 5,000 separate facts of the weather of a day, in North-western Europe and on the Atlantic.

ISOBARS

The distribution of pressure is almost universally shown by drawing isobars for sea-level; these are lines on the map connecting all the points at which the pressure, corrected for the height of the station above sea-level, has definite values. Such isobaric lines, or isobars, were formerly drawn on our maps for every tenth of an inch of barometric pressure given by a mercury barometer, so that the line marked 29·9 on a synchronous chart meant that, at the time of observation, the sea-level pressure computed from the reading for the epoch to which the map is intended to refer and adopted for any position crossed by the line, was 29·9 inches of mercury. For higher pressures

lines were drawn similarly for 30·0 inches, 30·1 inches, etc., and, ranging downwards, for 29·8 inches, 29·7 inches, etc. This practice is generally expressed by saying that isobars are drawn for every tenth of an inch. With the change of measurement of pressure from inches to millibars, a corresponding change has to be made in the setting out of the lines. On the maps of the British Section of the Daily Weather Report isobars are drawn for the datum pressure of 1,000 millibars, the C.G.S. atmosphere, and for each step of two millibars upwards and downwards from that datum; the maps of the International Section carry isobars for 1,000 millibars and for steps of four millibars upwards or downwards from that datum. The scale of the map of the British Section is double that of the International Section so that a step of two millibars of pressure in the one case would give the same actual distance on the map as a step of four millibars in the other.

The process of drawing isobars is, however, exactly similar whatever unit and whatever map be adopted. It is, of course, unusual for the reading at a station to fall on the exact millibar, still more so on an exact two-millibar or four-millibar step. The position of the point to be adopted for the exact step has generally to be determined from the readings at stations on either side of it. Readings are reported and plotted for the nearest tenth of a millibar, and the estimation of the point for the exact step between two stations, one of which has a reading above the step and the other below it, presents little difficulty. The process is known in this relation as interpolation, and a little practice only is necessary to give a result which is sufficiently accurate, except in special cases where there are local variations of pressure not indicated by the available readings. Sometimes several isobaric lines have to be interpolated between two adjacent stations. It requires some skill and judgment to draw a series of isobars quickly and correctly. In examining them it is important to recollect, as one runs the eye along the isobar, that if in any part of its course the pressure is lower on the left than on the right, it

can never be otherwise in any other part of the course. An isobar can never stop short; it must sooner or later re-enter on its path, either within the map or beyond it. It may have to go round the earth's axis to take up the end again. It cannot bifurcate except in the highly improbable event of the one line of the bifurcation being the limiting case of a linear distribution of *maximum* or *minimum* pressure. It is just possible but not likely that an isobar for an exact number of millibars might cross its own path and make a figure of 8, in which case, for reasons which will presently be apparent, the crossing point must be a region of no wind.

The reduction of barometer readings to sea-level is necessary, because pressure diminishes with height at about the rate of one-tenth of a millibar for a metre or a tenth of an inch of mercury for 100 feet, so that the variations due to moderate heights are of a greater order of magnitude than those of the ordinary meteorological changes. When the heights are great there is no doubt considerable risk of uncertainty introduced by reduction to sea-level; but except for a few high-level stations, the reduction was adopted for daily weather maps by all countries except the Transvaal, where the heights of the stations were mostly of the order of 4,000 or 5,000 feet, and were not accurately known. For the Transvaal daily weather service deviation from average was used for plotting, instead of pressure-values at sea-level. It may easily be argued that for the higher continental areas it would be better to have a separate chart for some higher level, 1,000, 3,000, or 5,000 feet, and not attempt to join up the lines with those drawn for the sea and for land areas that are not higher than 500 feet, but the interesting experiment of a dual system for mapping has not yet been tried. There is much to be said for using the level of 106 metres above sea-level as the horizontal plane for meteorological charts because that would correspond with a standard pressure of 1,000 millibars and the corrections for height would be less.

ISOGRAMS

The distribution of other elements, such as temperature or humidity, can also be represented by lines which are drawn through points at which the element has a specified value. The general name of isogram is given to a line drawn on a diagram or chart separating the region of values above a certain fixed limit from those below. Isobars are isograms of pressure, isotherms are isograms of temperature, and so on.

The information represented by synchronous charts used for the purpose of forecasting is communicated by telegraph (wire or wireless) from the stations where the observations are made. A sufficient number of stations is required for the isobars to be drawn with reasonable accuracy. The map is very sensitive to errors. As a rule there are sufficient stations to enable the map-maker to detect an error of two or even one millibar by comparison with the readings of neighbouring stations. But it is not always so. I have known an undetected error of a tenth of an inch (three millibars) in the reading at a single station result in the issue of an erroneous set of forecasts suggesting thunderstorms which did not occur.

It is of vital importance in forecasting that the observations which reach the forecaster should be free from errors of reading or transmission, otherwise the finer structure of the atmospheric situation is lost, and a generalised map is produced day after day in which exceptional readings, whether true or false, are rounded off. Progress in accuracy then becomes practically impossible. Hence it will be found that a large part of the work of dealing with synchronous observations has to be devoted to the preliminary duties of testing and comparing instruments, inspecting stations, and checking the accuracy of telegrams. The organisation is the more difficult because the observers themselves sometimes have no practice in plotting observations on charts, and they are apt to think that a suggestion from London of a doubt as to the accuracy of barometer-readings made on the spot displays an unjustifiable want of confidence.

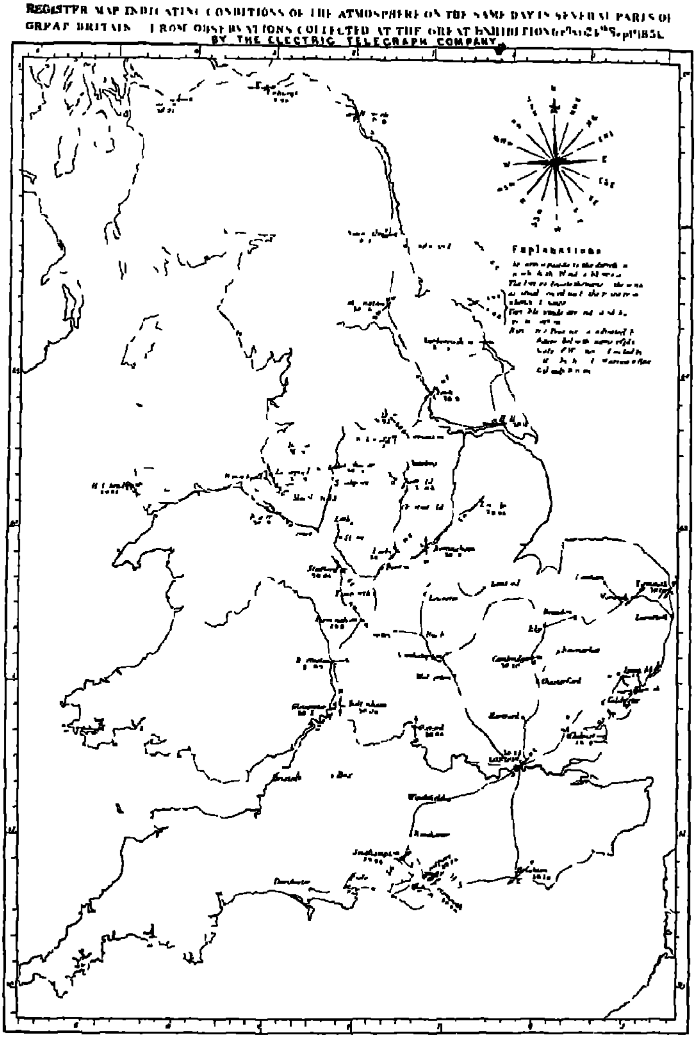


Fig. 1.—Synchronous Weather Chart, compiled at the Exhibition of 1851. (M. O. Library.)

For an historical account of the development of the daily synchronous chart and the gradual progress towards the present system of gale-warnings and weather-forecasts, the reader may be referred to the standard work on dynamical meteorology by H. H. Hildebrandsson and L. Teisserenc de Bort, "Les Bases de la Météorologie Dynamique," Vol. I. Chap. IV.

I shall not attempt here to recapitulate the history, which goes back at least to the time of Lavoisier in the eighteenth century. Naturally the development received its greatest impetus with the introduction of the electric telegraph. I will confine myself to reproducing one or two examples of notable charts. The first, the chart for 9 a.m., September 24, 1851, is one of a series of charts produced in connection with the great Exhibition of 1851 (Fig. 1), and may be regarded as the sequel of an experiment in weather telegraphy initiated by the *Daily News* in 1849. The winds are represented by arrows and the pressures are written in figures, while the weather is indicated by letters.

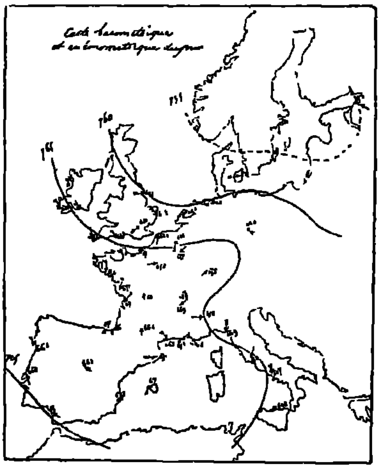


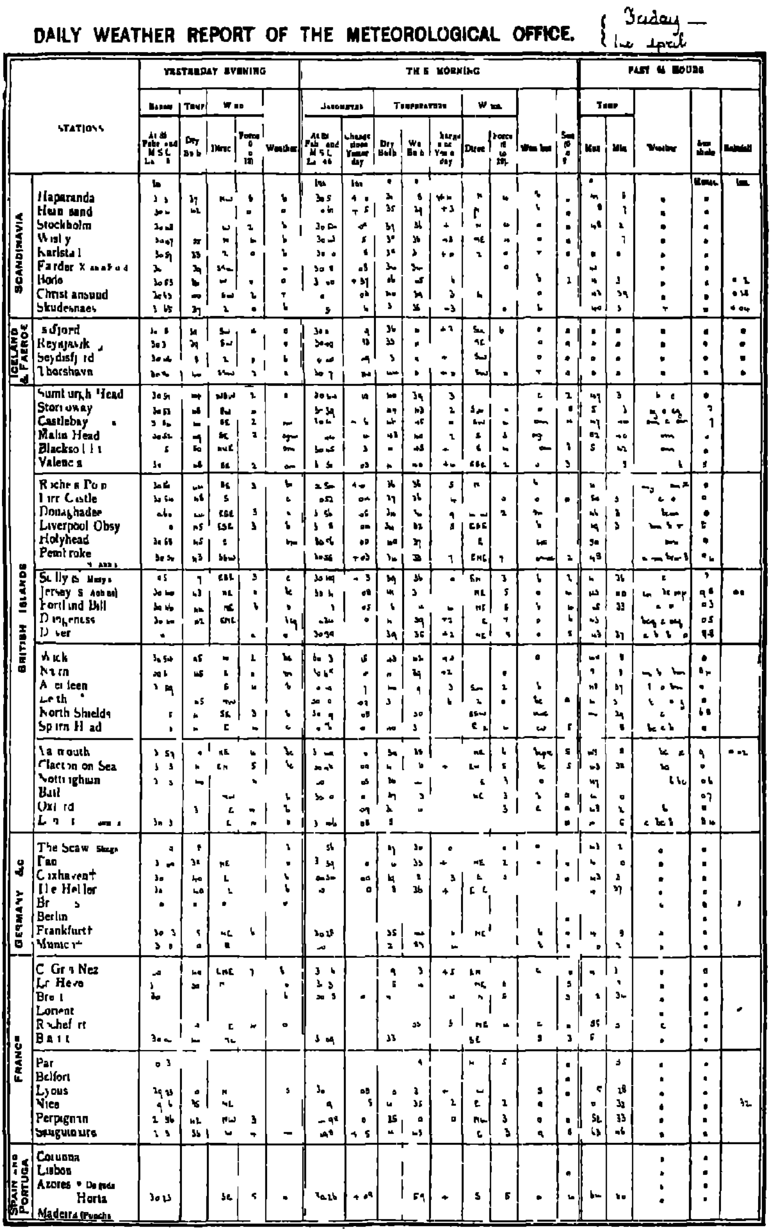
FIG. 2.—Weather Map with Isobars. Observatoire de Paris, 1863.

The next example, the frontispiece of the first edition, was prepared in 1860 by Admiral FitzRoy, head of the Meterological Department of the Board of Trade, one of a series representing the storm of October 25-26, 1859, in which the *Royal Charter* was wrecked. The third (Fig. 2) is one of the earliest charts for Western Europe, as organised by Leverrier, the originator of international weather telegraphy. It was published in the autumn of 1863 in the " Bulletin International de l'Observatoire de Paris."

Admiral FitzRoy's chart indicates the barometric pressure and the temperature by the lengths of ordinates drawn upwards from the parallels of latitude, whereas Leverrier's chart indicates the adoption of the isobar as the main feature of the chart. The difficulty of obtaining the material for the construction of synoptic charts for any considerable area has always been very great. For the efficient working of an international system there are many requirements—simultaneity of observations, effective and sympathetic telegraphic organisation, uniformity of instruments, methods of observing and of reducing observations, and, finally, if the system is to be really international, uniformity of units. Since 1851, when the first synchronous telegraphic chart was exhibited, gradual progress has been made towards the fulfilment of all these conditions by individual countries and by international agreement between European countries.

In its chief features the system of charts which is in general use had become established in 1872, and from that time it has been gradually improved. In 1910 it was represented by daily charts and reports issued by this country partly in C.G.S. and partly in British units, and, on the Continent, by Portugal, Spain, France, Germany, Austria, Italy, Norway, Sweden, Denmark, Holland, Belgium, Switzerland, Hungary, Roumania, Russia, in metric units. Meanwhile in the western hemisphere a uniform system based on British units was in use for the vast combined area of the United States and British North America, in the eastern hemisphere for the area represented geographically by India, and at the Antipodes for the Australian continent and adjacent islands. Daily reports were collected in South Africa, but the Union had not yet established a regular issue of daily charts. Daily reports and charts using metric units were issued in Algeria, Egypt, Japan, China, and the Argentine Republic.

We note on October 30, 1922:—Belgium, Egypt, Great Britain, Norway and Spain now use millibars; Australia gives inches with millibar equivalents. The Argentine Republic gives isobars for steps of four millibars from 1,000 millibars upwards and downwards, but gives its data in millimetres. France



DAILY WEATHER REPORT OF THE METEOROLOGICAL OFFICE. Today — 1st April

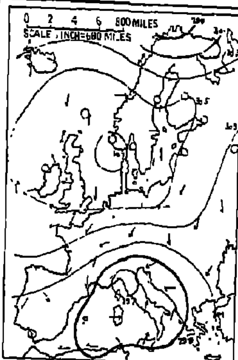
Region	Stations	Yesterday Evening	This Morning	Past 24 Hours
Scandinavia	Haparanda	[illegible]	[illegible]	[illegible]
	Hernösand	[illegible]	[illegible]	[illegible]
	Stockholm	[illegible]	[illegible]	[illegible]
	Wisby	[illegible]	[illegible]	[illegible]
	Karlstad	[illegible]	[illegible]	[illegible]
	Farder	[illegible]	[illegible]	[illegible]
	Bodo	[illegible]	[illegible]	[illegible]
	Christiansund	[illegible]	[illegible]	[illegible]
	Skudesnaes	[illegible]	[illegible]	[illegible]
Iceland & Faeroe	Isafjord	[illegible]	[illegible]	[illegible]
	Reykjavik	[illegible]	[illegible]	[illegible]
	Seydisfjord	[illegible]	[illegible]	[illegible]
	Thorshavn	[illegible]	[illegible]	[illegible]
British Islands	Sumburgh Head	[illegible]	[illegible]	[illegible]
	Stornoway	[illegible]	[illegible]	[illegible]
	Castlebay	[illegible]	[illegible]	[illegible]
	Malin Head	[illegible]	[illegible]	[illegible]
	Blacksod	[illegible]	[illegible]	[illegible]
	Valencia	[illegible]	[illegible]	[illegible]
	Roches Point	[illegible]	[illegible]	[illegible]
	Birr Castle	[illegible]	[illegible]	[illegible]
	Donaghadee	[illegible]	[illegible]	[illegible]
	Liverpool Obsy	[illegible]	[illegible]	[illegible]
	Holyhead	[illegible]	[illegible]	[illegible]
	Pembroke	[illegible]	[illegible]	[illegible]
	Scilly (St Marys)	[illegible]	[illegible]	[illegible]
	Jersey (St Aubin)	[illegible]	[illegible]	[illegible]
	Portland Bill	[illegible]	[illegible]	[illegible]
	Dungeness	[illegible]	[illegible]	[illegible]
	Dover	[illegible]	[illegible]	[illegible]
	Wick	[illegible]	[illegible]	[illegible]
	Nairn	[illegible]	[illegible]	[illegible]
	Aberdeen	[illegible]	[illegible]	[illegible]
	Leith	[illegible]	[illegible]	[illegible]
	North Shields	[illegible]	[illegible]	[illegible]
	Spurn Head	[illegible]	[illegible]	[illegible]
	Yarmouth	[illegible]	[illegible]	[illegible]
	Clacton on Sea	[illegible]	[illegible]	[illegible]
	Nottingham	[illegible]	[illegible]	[illegible]
	Bath	[illegible]	[illegible]	[illegible]
	Oxford	[illegible]	[illegible]	[illegible]
	London	[illegible]	[illegible]	[illegible]
Germany &c	The Skaw	[illegible]	[illegible]	[illegible]
	Fano	[illegible]	[illegible]	[illegible]
	Cuxhaven	[illegible]	[illegible]	[illegible]
	The Helder	[illegible]	[illegible]	[illegible]
	Brussels	[illegible]	[illegible]	[illegible]
	Berlin	[illegible]	[illegible]	[illegible]
	Frankfurt	[illegible]	[illegible]	[illegible]
	Munich	[illegible]	[illegible]	[illegible]
France	C. Gris Nez	[illegible]	[illegible]	[illegible]
	Le Havre	[illegible]	[illegible]	[illegible]
	Brest	[illegible]	[illegible]	[illegible]
	Lorient	[illegible]	[illegible]	[illegible]
	Rochefort	[illegible]	[illegible]	[illegible]
	Biarritz	[illegible]	[illegible]	[illegible]
	Paris	[illegible]	[illegible]	[illegible]
	Belfort	[illegible]	[illegible]	[illegible]
	Lyons	[illegible]	[illegible]	[illegible]
	Nice	[illegible]	[illegible]	[illegible]
	Perpignan	[illegible]	[illegible]	[illegible]
	Sanguinaire	[illegible]	[illegible]	[illegible]
Spain and Portugal	Corunna	[illegible]	[illegible]	[illegible]
	Lisbon	[illegible]	[illegible]	[illegible]
	Azores (Horta)	[illegible]	[illegible]	[illegible]
	Madeira (Funchal)	[illegible]	[illegible]	[illegible]

FIG. 3. Reduced facsimile of the Daily Weather Report of April 1, 1910

Supplementary Charts of Barometer and Wind for 7 A.M. and 6 P.M. Yesterday

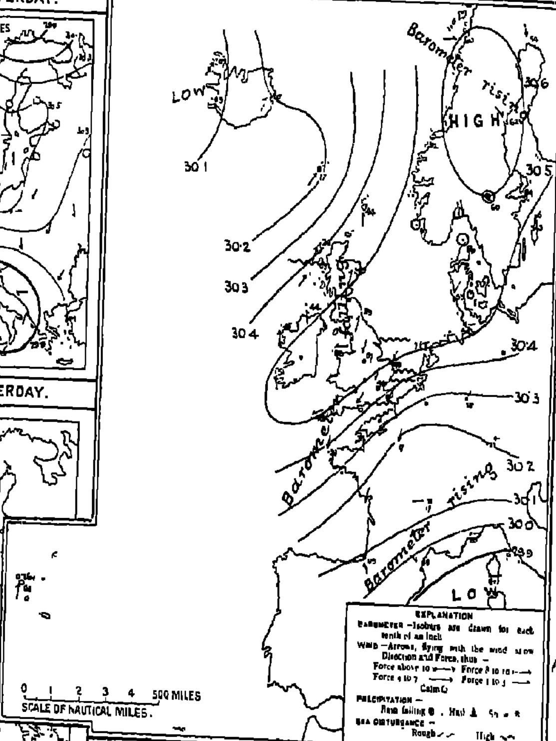
Friday. WEATHER 1st April.

7 A.M. Yesterday.



6 P.M. Yesterday.

1. Barometer, Wind and Sea at 7 A.M. To-Day.



Averages of Temperature at 8 A.M. for the Two Monthly Period March – April

(Derived chiefly from Observations extending over (i.e. 35 years—1871-1905))

Notes on the General Situation at 7 A.M.

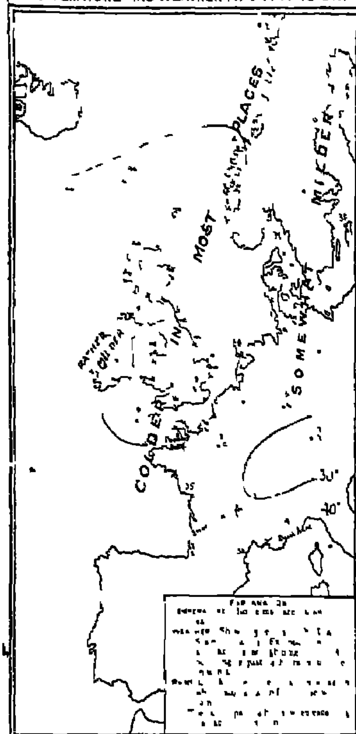
Pressure has decreased over the United Kingdom France and the Icelandic region while it has risen in the north of Scandinavia and the readings are now above 30·6 in over a considerable portion of both Sweden and Norway. The anticyclone system extends in a southwesterly direction across the North Sea England and Ireland. The barometer is below 30·10 in in the west of Iceland and below 29·9 ins in Corsica.

The wind continues N.E.ly over the Baltic Germany, the Low Countries, France and the southern half of England. Generally it is moderate in force but blows a fresh or strong breeze over the Channel and southeast of England and a high wind at Dungeness. Over Scotland, Ireland and thence to Iceland the wind is S.ly to S.W.ly light generally fresh in places. Temperature has undergone little change as a whole. Over these islands it ranges from 47° at Blacksod Point to below 40° generally and to 31° at North Shields. The weather is overcast in some localities, but generally it is fair to fine and bright. Snow is reported at Biarritz and Lyons and rain at Karlstad and Thorshavn.

CHARTS

WEATHER PROSPECTS.

2 TEMPERATURE AND WEATHER AT 7 A M TO DAY



FORECASTS FOR THE 24 HOURS NOON TO NOON

THE FURTHER OUTLOOK

0 a b
1
2 a b
3
4 a b
5
6 a b
7 a b
8 a b
9 a b
10 a b

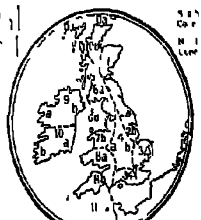
11 WESTERN CHANNEL AND BAY

NOTES ON YESTERDAYS WEATHER

GENERAL INFERENCE FROM THE 7 A M OBSERVATIONS

The anticyclone will ...

FORECAST DISTRICTS



DAILY WEATHER REPORT. Friday 1st April — 1910

TEMPERATURE, WEATHER, SUNSHINE AND RAINFALL FOR YESTERDAY.

STATIONS	Temperature F Max.	Temperature F Min.	Weather	Sunshine H.	Rainfall I.
Oban to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Dublin (City) to 6 p.m.	[illegible]		[illegible]		
Rossall Beach to 6 p.m.	[illegible]	35	c		–
Blackpool to 9 p.m.	[illegible]	38	[illegible]	[illegible]	
Southport to 9 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	–
Rhyl to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Colwyn Bay to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Llandudno to 9 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Bettws y Coed to 6 p.m.	[illegible]		[illegible]	[illegible]	
[illegible] to 6 p.m.					
Aberystwyth to 6 p.m.	[illegible]	[illegible]		[illegible]	
[illegible] to 6 p.m.	[illegible]		[illegible]		
[illegible] to 6 p.m.		[illegible]	[illegible]	[illegible]	
[illegible] to 6 p.m.	[illegible]	[illegible]		[illegible]	
Weymouth to 6 p.m.	[illegible]		[illegible]	[illegible]	
Bournemouth to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Southsea to 6 p.m.	[illegible]	55		[illegible]	
Bognor to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	

STATIONS	Temperature F Max.	Temperature F Min.	Weather	Sunshine H.	Rainfall I.
Worthing to 6 p.m.	[illegible]	[illegible]	[illegible]		
*Brighton to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Seaford to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
*Eastbourne to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Bexhill on Sea to 9 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Hastings	[illegible]		[illegible]	[illegible]	[illegible]
*Folkestone to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
†Deal to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Ramsgate to 6 p.m.	[illegible]		[illegible]	[illegible]	
Margate to 6 p.m.	[illegible]	[illegible]		[illegible]	
Felixstowe to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible] to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
*Skegness to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Scarborough to 9 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Harrogate to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
†Buxton to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Darwen to 6 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	
Manchester to 9 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] to 9 p.m.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TEMPERATURE, WEATHER, and RAINFALL at additional FOREIGN STATIONS, mainly for the 24 hours ended at 7 a.m. yesterday

STATIONS	Temperature F Max.	Temperature F Min.	Weather	Rain
Madeira	[illegible]	[illegible]	[illegible]	Ins.
Marseilles	[illegible]	[illegible]	[illegible]	
Malta	[illegible]		[illegible]	–
Algiers	[illegible]	50	[illegible]	
Tunis	[illegible]	[illegible]		
Palermo	[illegible]	[illegible]	[illegible]	
Naples	5[illegible]	[illegible]	[illegible]	
Brindisi	[illegible]	[illegible]	[illegible]	
Rome	[illegible]	[illegible]	[illegible]	
Vienna	[illegible]	23	[illegible]	[illegible]
St. Petersburg	[illegible]	[illegible]	[illegible]	

STATIONS	Temperature F Max.	Temperature F Min.	Weather	Rain
[illegible]	[illegible]	[illegible]	[illegible]	Ins.
Groningen	[illegible]	[illegible]	[illegible]	[illegible]
Zurich			[illegible]	[illegible]
Geneva	[illegible]		[illegible]	
Lugano		[illegible]	[illegible]	
Dome	[illegible] 43		[illegible]	[illegible]
Cairo		[illegible]	[illegible]	
Casablanca	[illegible]	[illegible]	[illegible]	
Dakar	[illegible]		[illegible]	

WIRELESS TELEGRAMS — Received during the 24 hours ended at 9.30 a.m. to-day.

Ship and Hour of Observation	Position Lat.	Position Long.	Reading Bar.	Wind Dir.	Wind Force	Weather	Temperature Air Dry Bulb	Temperature Air Wet Bulb	Temperature Sea	Sea Disturbance	Ship and Hour of Observation	Position Lat.	Position Long.	Reading Bar.	Wind Dir.	Wind Force
[illegible]	°	°	Ins.				°	°	°			°	°	Ins.		

NOTES REFERRING TO INFORMATION GIVEN ON PAGE 1 —

(a) The morning observations are at 7 a.m. Western European time (French Stations 6.51 a.m.) with the following exceptions: Birr Castle and Oxford 8 a.m. Lisbon 8 a.m. local time Azores 6 a.m. local time.

(b) The information relating to weather is indicated by the following letters—b blue sky, bc [illegible] half clouded, c sky three parts clouded, d drizzling rain, e wet air without rain falling, f fog, g gloomy, h hail, l lightning, m misty hazy, o overcast, p passing showers, q squally, r rain, s snow, t thunder, u ugly threatening, v visibility unusual transparency, w dew, x hoar frost, z dust haze or smoke.

* Information for these columns is not usually received.

† The figures in the wet bulb column represent the relative humidity.

‡ Received too late for [illegible] Charts.

TERMS OF SUBSCRIPTION for the Daily Weather Report and for transmission of Forecasts by telegraph may be obtained on application.

METEOROLOGICAL OFFICE
63 VICTORIA STREET S.W.

W. N. SHAW (*Director*)

published maps in millibars for a time, but has reverted to millimetres. U.S.A. used millibars and tercentesimal scale for maps of the northern hemisphere in 1914; Mexico has resumed the issue of a daily report in millimetres. South Africa still uses inches.

Thus the Daily Weather Report and its accompanying charts, which sixty years ago in this country formed the subject of the prospectus of a limited company, has become a recognised Government institution over nearly the whole of the civilised world, with the object of disseminating telegraphic information as to the present state of the weather and the prospects of the immediate future.

The reader, therefore, will understand that a book on lines similar to this one might have been written in almost any language, with illustrations drawn entirely from the weather charts of other countries.

THE DAILY WEATHER REPORT OF THE METEOROLOGICAL OFFICE, 1910—1919

Let us first turn our attention to the information which was included in the older daily reports of this country and the form in which it was presented. Except as regards colour, the blue tinting of the sea area being omitted, Fig. 3 is a facsimile reproduction on a reduced scale of the report for April 1, 1910, which embodied the most recent modifications.[1] The construction of the report will be better understood if I make it clear that the fundamental principle adopted by the Office with regard to the issue of gale warnings and forecasts was that the issues must be accompanied by the data upon which the warnings or forecasts are based and a statement of the reasons for the conclusions expressed therein. Page 1 of the Daily Weather Report contained the data received by telegraph from twenty-nine British stations, thirty-one continental stations, and seven stations in the Atlantic islands of Iceland, Faröe, Azores, and Madeira. With the exception of only four stations, two of them in our islands, the

[1] The form of the Daily Weather Report was again revised for January 1. 1911, but as the illustrations were drawn mainly from charts of the same form as that of April 1, 1910, the reference thereto has been retained.

morning observations were at 7 a.m. Western European, or Greenwich mean time. The evening observations, which occupy the first five columns, were at 6 p.m. in this country, but they are less strictly synchronous with those of other countries than are the morning ones.

The information was telegraphed to the Office in code form. The code was a figure code, five figures forming a "group." The component figures may be represented as follows :—

BBB	Three figures representing pressure to the hundredth of an inch with the first figure (which will be 2 or 3) omitted.
DD	Two figures for wind direction in even points—02 is NNE, 08 is E, 16 is S, 24 is W, 32 is N.
FF	Two figures for wind-force on the Beaufort scale 0 to 12 (see p. 20).
W	One figure indicating the weather or the state of the sky according to a conventional figure code.
TT	Two figures for temperature of the air in Fahrenheit degrees.
tt	Two figures for the temperature of the wet bulb.
RRR	Three figures for the rainfall to the hundredth of an inch.
T′T′	Two figures for the maximum temperature of the previous twenty-four hours.
t′t′	Two figures for the minimum temperature of the previous twenty-four hours.
S	One figure for the state of the sea according to a conventional scale

The form of the message was arranged by international agreement and a full morning message consisted of six groups of figures. The first two groups gave the observations of the barometer, wind-direction and force, dry bulb temperature, and weather of the previous evening, represented by BBBDD FFWTT.

The four following groups gave the morning observations and the information as to maximum and minimum temperatures, rainfall and sea-disturbance in the past twenty-four hours: BBBDD FFWTT ttRRR T′T′t′t′S.

Negociations, in progress since 1909, for replacing the figures used to give the temperature of the wet bulb by the change in the barometric pressure in the three hours preceding the hour of the morning observation had been completed, and the consequent modification of the international code began on May 1, 1911.

Additional information about the duration of sunshine and

the weather in the past twenty-four hours was given in the British messages by additional groups or in words.

Particulars as to the Beaufort scale of wind-force, which is used as a basis of the figure-code for wind, are given in a later section of this chapter, pp. 17—22.

The other figure-codes were as follows :—

WEATHER CODE.

0 = sky quite clear.	5 = rain falling.
1 = „ a quarter clouded.	6 = snow falling.
2 = „ half clouded.	7 = haze.
3 = „ three-quarters clouded.	8 = fog.
4 = „ entirely overcast.	9 = thunderstorm.

SEA-DISTURBANCE CODE.

Scale.	Description.	Height of waves in feet from crest to trough.	Condition of Surface.
0	Calm . . .	—	Glassy.
1, 2	Smooth . .	—	Rippled.
3, 4	Slight to moderate	Under 5 feet	Rocks buoy or small boat. Furrowed.
5, 6	Rough to very rough.	5 to 10 feet	Much disturbed; deeply furrowed.
7, 8	High to very high	11 to 15 feet; 16 to 35 feet	Rollers with steep fronts.
9	Phenomenal . .	36 feet and above	Precipitous; towering.

WIND-DIRECTION CODE.

00 Calm.

02 NNE.	18 SSW.
04 NE.	20 SW.
06 ENE.	22 WSW.
08 E.	24 W.
10 ESE.	26 WNW.
12 SE.	28 NW.
14 SSE.	30 NNW.
16 S.	32 N.

The positions of the digits in the groups were rigidly adhered to; a missing digit was represented by a zero. The six groups indicated above were the international groups. For our own use we employed additional groups, for example, three figures to give the duration of sunshine in hours, two for the maximum

temperature between 7 a.m. and 6 p.m., a group of five figures for the maximum or minimum of pressure since last observation and the time of its occurrence as taken from the barographic record. We also had a special code for transmitting information respecting cirrus clouds.

For information coming from continental countries the code was modified in some particulars in order to transmit the corresponding information in metric units. The readings thus received were converted to the British equivalents by the official who received the message.

The remaining data available for the morning report were given in three tables on its fourth page. The first table gave information for about thirty-eight additional British or Irish stations received by telegram on the previous evening or by first post in the morning. The second gave information extracted from the "Bulletin International" of France for stations in Europe or Africa which were then outside the range of our own telegraphic reports. This table was introduced into the report at the request of the late Sir W. Harcourt, sometime Chancellor of the Exchequer. The third table on p. 4 is the most recent and most interesting, because it gives information received by radio-telegraphy from the ships of H.M. Navy, or from the liners crossing the Atlantic. Information was sent from H.M. ships in accordance with a code adopted in 1907, similar to that used for shore-stations. From January, 1909, messages were also received from Atlantic liners in accordance with a modification of the code to suit the special circumstances. The information in this table is necessarily spasmodic, because it depends upon the ships being within practicable range of the shore-stations at the time of observation, either directly or by repetition of the message through an intervening ship, but the readings always refer to 7 a.m. or 6 p.m., with the supplementary information of a previous reading, so that whenever messages arrived the data could be incorporated on the chart with those from continental or island stations, and thus the gaps in our information for

the region between our shores and the Atlantic islands were occasionally filled in a very satisfactory manner.

Pages 2 and 3 of the Daily Weather Report showed the charted data, with remarks and conclusions drawn from them.

The first chart shows the pressure-readings and the isobars for sea-level pressure, with indications of the changes that are taking place at the time of observation. The isobar for 29·9 in. is marked by a thicker line, because the pressure indicated thereby is an approximation to the average sea-level pressure over our area. This isobar is shown somewhere on nearly every map. A glance at its relative position on two successive maps is enough to give a general idea of the changes which have taken place in the interval. The positions at sea from which information has been received by radio-telegraphy are indicated by a symbol suggesting a two-funnel steamer. The wind-circulation is represented by arrows, rough sea by a bold wavy line; the distribution of rainfall or other kinds of precipitation is made conspicuous by marking the several stations with a black dot for rain, a star for snow, and a black triangle for hail.

Temperature and weather are represented on the second chart, the temperature by figures, with isotherms for every ten degrees, and the weather at the time of observation by letters in accordance with the following convention, which is based on Admiral Beaufort's notation:—

b. Blue sky.
bc. Sky half clouded.
c. Sky three parts clouded.
d. Drizzling rain.
e. Wet air without rain falling.
f. Fog.
g. Gloom.
h. Hail.
l. Lightning.
m. Mist.
o. Overcast sky.
p. Passing showers.
q. Squalls.
r. Rain.
s. Snow.
t. Thunder.
u. Ugly, threatening appearance of the sky.
v. Visibility, unusual transparency.
w. Dew.
x. Hoar frost.
z. Dust-haze, or smoke.

Information as to changes in temperature and the distribution of rainfall is written in words on the chart.

Supplementary charts on a smaller scale are given to show the distribution of pressure and wind at 7 a.m. and 6 p.m. "yesterday." In these the points of the wind-arrows mark the position of observation, whether on land or at sea.

On p. 2 of the report a chart of mean monthly temperature at 8 a.m. is given for the purpose of reference, and balancing it on the opposite page is a chart, upon which information is given as to the division of the country into districts for forecast purposes and as to the notification of gale-warnings.

The text of the report consisted of a series of notes on the general meteorological situation as disclosed by the data for 7 a.m., and by the charts which are based on them, together with a short note on yesterday's weather. These remarks were intended primarily for the use of evening newspapers, whose readers have not access to the charts or tables of data; and, secondarily, for readers of the report who are not accustomed to formulate for themselves a summary of the information displayed in the tables or the charts. So far as the Office is concerned, they served the purpose of impressing upon the forecaster's mind the salient features of the meteorological situation in a definite form, and their preparation, therefore, leads to precision of ideas respecting the general situation.

The inference which is drawn from the situation by comparison with those represented by previous maps is then expressed in brief under the heading "General Inference from the 7 a.m. Observations" which appears on the third page. The forecasts which express the application of the general inference to the prospects of weather for the ensuing twenty-four hours within the special areas represented by the several districts of the British Isles were set out in a column under the heading of "Weather Prospects." On April 1, 1910, for the first time, in the report here reproduced, a column appeared on the extreme right hand for the insertion of a note on the "Further Outlook," thus extending the prospect of weather, but in a more general sense, to the period beyond the termination of the twenty-four hours. This column was

used if the meteorological conditions were such as to enable the forecaster to draw a reasonable inference for the longer period. If not, the column was left blank.

Before we proceed to the consideration of the changes that were introduced during the interval between 1911 and 1921 the remarks in this chapter must be supplemented by an explanation of the present position in respect of measurements of wind-velocity and estimations of wind-force because the wind has become an object of very special consideration. It is even more so now than it used to be when the chief interest in winds was from the point of view of ships. Much progress has been made in the study of all subjects connected with wind. Anemometers, which used to be very rare instruments, are now, comparatively speaking, common, though they are still expensive. At the same time the estimation of wind without instruments is an accomplishment which can be easily acquired and turned to useful account.

The following notes are based upon a memorandum contributed to the Advisory Committee for Aeronautics in 1909.

THE BEAUFORT SCALE OF WIND-FORCE AND THE FORMULÆ USED IN ANEMOMETRY

The scale in general use on sea and land for estimating wind-force is that devised in 1805 by Admiral Sir Francis Beaufort, Hydrographer of the Navy. The original specification of the scale was based upon the speed which a well-conditioned man-of-war would make, and the amount of sail she could carry. Since the formation of the scale the practice of estimating by it has been extended from sea to land; but changes in the rig of sailing-vessels and their gradual replacement by steam-vessels have made the original specification no longer applicable in practice, and by 1903 this method of estimation had become simply traditional.

After a careful comparison, completed in 1903, of the practice of experienced observers with the records of anemometers, a scale of equivalents has been ascertained which gives results agreeing closely with the following formulæ for the

velocity and pressure equivalents of the Beaufort scale of wind force :—

$$P = \cdot003V^2 = \cdot0105B^3, \qquad V = 1\cdot87\ \sqrt{B^3},$$

where B is the Beaufort number, V the corresponding velocity in miles per hour, P the corresponding pressure in lbs. per square foot.

When metric units are used and v is the velocity in metres per second, f the force per square centimetre in millibars, we have instead :—

$$f = \cdot0072v^2 = \cdot005B^3 \text{ and } v = 0\cdot836\ \sqrt{B^3}\,;$$

hence a wind of force 6 on the Beaufort scale gives a pressure on the small area exposed to it of 1·1 millibar.

These formulæ were adopted by the Meteorological Office to express the relations of B, V, and P, and from them the scale of average equivalents given in the table on pp. 68, 69, has been prepared. At the same time an endeavour was made by the late Captain Campbell Hepworth, Marine Superintendent of the Office, to translate the original specification of the Beaufort scale into terms that are applicable in the case of modern ships, and by Dr. G. C. Simpson, who is now Director of the Office, to suggest a classification by means of the effects upon trees and buildings corresponding with the various Beaufort numbers. This classification does not admit of definition in precise terms, and it is open to criticism on that ground. But in the absence of any special apparatus general terms must be used, and the classification is found in practice to provide fair working rules for observers on land.

A note must be added as to the factor employed for the reduction of the anemometer readings in computing the formulæ given above, in explanation of the second column of the table of wind velocities, p. 22. Originally the factor 3 was used for all anemometers of the Robinson type to convert the "run of the cups" to the "run of the wind." Experiments, chiefly as regards this country, by Mr. W. H. Dines, F.R.S., showed that the factor 3 is too large for the larger types of

Robinson anemometers, and after prolonged inquiry the factor 2·2 has been adopted for the Robinson anemometer of standard pattern, *i.e.*, with 9-inch cups and 24-inch arms, measured from the axis to the centre of the cup. Smaller instruments are found to require a higher factor, up to 2·8 for the recording instrument of smaller size, *i.e.*, with 5-inch cups and 1-foot arms (see "Observer's Handbook," 1909, p. 77), or the sight-reading instruments that are in general use.

The pressure tube instrument (another form of anemometer used by the Meteorological Office) is graduated on the understanding that, with a wind of 100 miles per hour, the pressure at the vane and suction at the head give a difference of level of 7·3 inches of water upon a water gauge. Putting the statement as a formula, we get

$$W = \cdot 00073 V^2$$

where W is the difference in water level in inches produced in a water gauge, and V is the wind velocity in miles per hour.

In measurements of the highest refinement allowance ought to be made for the variation in the density of the air, but for the estimation of wind force such a correction would be beyond the practical limits of accuracy.

In recent years the recording of the wind by the pressure-tube anemometer has been greatly improved by adding apparatus for recording the direction of the wind upon the same drum. The original design of this addition, like that of the original apparatus for recording the velocity, is due to Mr. W. H. Dines, F.R.S. Recently new mechanism for actuating the direction-gear has been introduced into the official specification and a new form has been given to the vane of the recorder in order to promote its immediate alignment with the direction of the wind. The instrument in this form gives a remarkably interesting picture of the changes in the wind, not merely of its mean force and direction but also of the fluctuations in both elements which express what has come to be known as the gustiness of the wind.

The Beaufort Scale of Wind-Force.

Beaufort Number.	Admiral Beaufort's general description of wind	Admiral Beaufort's Specification, 1805.	Description of wind	Mode of estimating aboard sailing vessels.
0	Calm . .	Calm	—	—
1	Light air .	Just sufficient to give steerage way	—	—
2	Slight breeze	That in which a well-conditioned man-of-war, with all sail set and "clean full" would go in smooth water from 1 to 2 knots		
3	Gentle breeze	3 to 4 knots	Light breeze	Sufficient wind for working ship.
4	Moderate breeze	5 to 6 knots	Moderate breeze	Forces most advantageous for sailing with leading wind and all sail drawing
5	Fresh breeze	That to which she could just carry in chase "full and by" Royals, etc. .	—	—
6	Strong breeze	Single - reefed topsails or top - gallant sails	Strong wind	Reduction of sail necessary with leading wind
7	Moderate gale (*High wind*)[2]	Double - reefed topsails, jib, etc.		
8	Fresh gale . (*Gale*)[2]	Triple - reefed topsails, etc.	Gale forces	Considerable reduction of sail necessary even with wind quartering
9	Strong gale .	Close-reefed topsails and courses		
10	Whole gale .	That which she could scarcely bear with close - reefed main topsail and reefed foresail	Storm forces	Close reefed sail running, or hove to under storm sail
11	Storm .	That which would reduce her to storm stay-sails		
12	Hurricane .	That which no canvas could withstand	Hurricane	No sail can stand even when running

[1] The fishing smack in this column may be taken as representing a trawler of average type and trim. For larger or smaller boats, and for special circumstances allowance must be made.

[2] It has recently been decided that for statistical purposes winds of force less

Specification and Table of Equivalents.

Specification of Beaufort Scale.		Mean Wind Force in lbs. per square foot at standard density ($P = \cdot 0105 B^2$).	Equivalent velocity for expressing estimates in miles per hour ($V = 1 \cdot 87 \sqrt{B^3}$).
For coast use, based on observations made at Scilly, Yarmouth and Holyhead.	For use on land, based on observations made at Land Stations.		
Calm	Calm; smoke rises vertically	0	0
Fishing smack[1] just has steerage way	Direction of wind shown by smoke drift, but not by wind vanes	·01	2
Wind fills the sails of smacks, which then move at about 1—2 miles per hour	Wind felt on face; leaves rustle; ordinary vane moved by wind	·08	5
Smacks begin to careen, and travel about 3—4 miles per hour	Leaves and small twigs in constant motion; wind extends light flag	·28	10
Good working breeze; smacks carry all canvas, with good list	Raises dust and loose paper; small branches are moved	·67	15
Smacks shorten sail .	Small trees in leaf begin to sway; wavelets form on inland waters	1·31	21
Smacks have double reef in mainsail. Care required when fishing	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty	2·3	27
Smacks remain in harbour, and those at sea lie to	Whole trees in motion; inconvenience felt when walking against wind	3·6	35
All smacks make for harbour, if near	Breaks twigs of trees; generally impedes progress	5·4	42
—	Slight structural damage occurs (chimney pots and slates removed)	7·7	50
—	Seldom experienced inland; trees uprooted; considerable structural damage occurs.	10·5	59
—	Very rarely experienced; accompanied by wide-spread damage	14·0	68
—	—	Above 17·0	Above 75

than 8 shall not be counted as gales, and to avoid the ambiguity implied by the use of the term "moderate gale" for force 7 the Beaufort description has been modified for use in connection with the daily weather service by the substitution of the description in italics for forces 7 and 8.

The complete set of wind formulæ are here collected:

Robinson anemometer, standard size, factor 2·2.
,, ,, portable size, factor 2·8.

Pressure tube graduation	$W = \cdot 00073\, V^2$.
Wind-pressure and wind-velocity . .	$P = \cdot 003\, V^2$.
Wind-pressure and Beaufort numbers .	$P = \cdot 0105\, B^3$.
Wind-velocity and Beaufort numbers .	$V = 1 \cdot 87\, \sqrt{B^3}$.

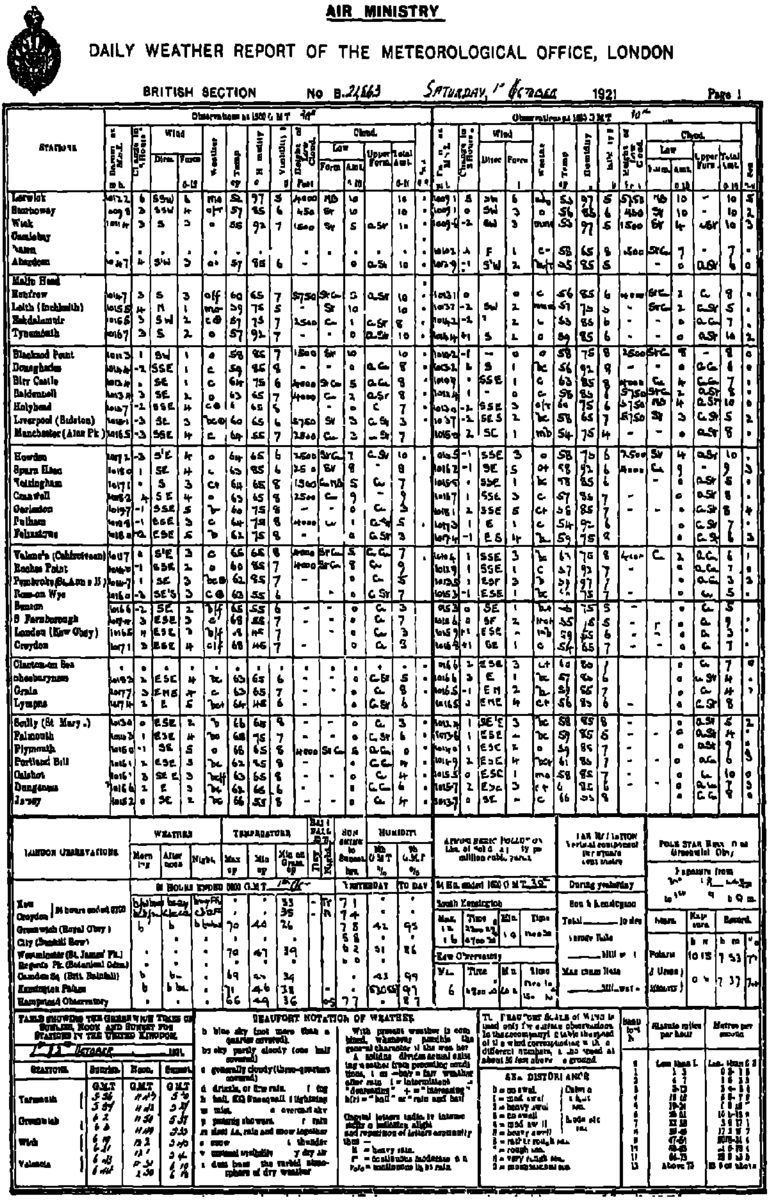
The units are the inch of water, the pound weight per square foot, and the mile per hour.

Using the formulæ given above and the table of mean values of the equivalents given on pp. 20, 21 the numbers have been obtained for specifying the limits of velocities in miles per hour, metres per second, and feet per second, corresponding with the several numbers of the Beaufort scale. They are given here.

Beaufort Number.	Statute Miles per hour.	Nautical Miles per hour.	Feet per second.	Metres per second.
0	Less than 1	Less than 1	Less than 2	Less than 0·5
1	1—3	1—3	2—5	0·5— 1·5
2	4—7	4—6	6—11	2—3
3	8—12	7—10	12—18	3·5— 5·5
4	13—18	11—16	19—27	6—8
5	19—24	17—21	28—36	8·5—10·5
6	25—31	22—27	37—46	11—14
7	32—38	28—33	47—56	14·5—17
8	39—46	34—40	57—68	17·5—20·5
9	47—54	41—47	69—80	21—24
10	55—63	48—55	81—93	24·5—28
11	64—75	56—65	94—110	28·5—33·5
12	Above 75	Above 65	Above 110	34 or above.

The table on pp. 20 and 21 gives the revised specification of the various numbers of the Beaufort scale for an anemometer with its vane at 30 feet above ground.

At the present time the Beaufort scale is less dominant than it used to be. Those who are interested in gunnery have for a long time been accustomed to deal with wind velocities in feet per second, and among naval officers there is a tendency to refer all velocity to miles per hour, either nautical miles or statute miles. For this reason the entry of the wind in Beaufort scale in the tables of the Daily Weather Report is translated into statute miles per hour in the map.



AIR MINISTRY

DAILY WEATHER REPORT OF THE METEOROLOGICAL OFFICE, LONDON

BRITISH SECTION No B. 21663 Saturday, 1st October 1921 Page 1

Stations: Lerwick, Stornoway, Wick, Castlebay, Nairn, Aberdeen, Malin Head, Renfrew, Leith (Inchkeith), Eskdalemuir, Tynemouth, Blacksod Point, Donaghadee, Birr Castle, Baldonnell, Holyhead, Liverpool (Bidston), Manchester (Alex Pk), Howden, Spurn Head, Yelvingham, Cranwell, Gorleston, Fulham, Felixstowe, Valencia (Cahirciveen), Roches Point, Pembroke, Ross-on Wye, Benson, S. Farnborough, London (Kew Obsy), Croydon, Clacton-on-Sea, Shoeburyness, Grain, Lympne, Scilly (St. Mary's), Falmouth, Plymouth, Portland Bill, Calshot, Dungeness, Jersey

LONDON OBSERVATIONS: Kew, Croydon, Greenwich (Royal Obsy), City (Bunhill Row), Westminster (St. James' Pk.), Regents Pk. (Botanical Gdns), Camden Sq. (Brit. Rainfall), Kensington Palace, Hampstead Observatory

TABLE SHOWING THE GREENWICH TIMES OF SUNRISE, NOON AND SUNSET FOR STATIONS IN THE UNITED KINGDOM: Yarmouth, Greenwich, Wick, Valencia

BEAUFORT NOTATION OF WEATHER

THE BEAUFORT SCALE OF WIND

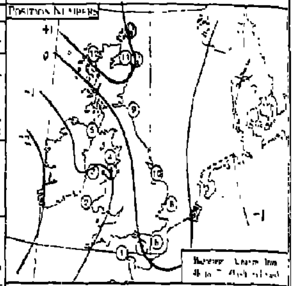
SEA DISTURBANCE

Fig. 4.—Reduced facsimile of the Daily Weather Report (British Section) of October 1, 1921.

STATIONS	Weather				Temperature			Rain	Sun			Hours
Lerwick	[illegible]	[illegible]	[illegible]	[illegible]	57	49		[illegible]	1	[illegible]	[illegible]	.
Stornoway	[illegible]	[illegible]	[illegible]	[illegible]	57	[illegible]	.	2	2	-	-	1 2
Wick	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.	[illegible]	-	1430	-	.
Castlebay							.					
Nairn	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]		-	-	-	-	6 6
Aberdeen	[illegible]	[illegible]	[illegible]		57	45	33	03	-	1450		[illegible]
Mull Head												
Renfrew	[illegible]	[illegible]	[illegible]	[illegible]	61	[illegible]	35	.	-	-	-	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26	.	-	-	-	.
Eskdalemuir	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36	-	-	-	.	[illegible]
Tynemouth	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5[illegible]		-	-	.	-	.
Blackpool Point	[illegible]	[illegible]	[illegible]	[illegible]	59	[illegible]	.	02	.	1600	.	.
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	-	.	.	.
Birr Castle	[illegible]	[illegible]	[illegible]		57	53	[illegible]	-	.	-	.	5 7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	.	.	.	[illegible]
Holyhead	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	57	[illegible]	[illegible]	.	1030	-	[illegible]
Liverpool	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41	-	.	.	-	5 8
Manchester	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	37	24	.	Trace	-	0130	.
Howden	[illegible]	[illegible]	[illegible]	F	65	[illegible]	32	-	.	-	-	[illegible]
Spurn Head	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5[illegible]	.	.	-	.	.	[illegible]
Nottingham	[illegible]	[illegible]	[illegible]		65	37	35	-	-	-	-	[illegible]
Cranwell	[illegible]	[illegible]	[illegible]	[illegible]	65	39	[illegible]	-	[illegible]	-	[illegible]	[illegible]
Gorleston	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	39	.	.	.	.	6 0
Pulham	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	36	-	-	-	.	4 4
Felixstowe	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	43	-	-	.	-	6 2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	57	51	06	[illegible]	[illegible]	2200	[illegible]
Roches Point	[illegible]	[illegible]	[illegible]	[illegible]	62	54		-	[illegible]	-	.	
Pembroke	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	.	-	-	-	-	5 6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35	30	.	[illegible]	-	.	5 7
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	35	30	-	-	.	.	.
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	33	[illegible]	.	[illegible]	-		[illegible]
London	[illegible]	[illegible]	[illegible]	[illegible]	70	[illegible]	[illegible]	-	Trace	.	-	[illegible]
Croydon	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	35	-	Trace	.	-	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	62	53	48	-		-	-	[illegible]
[illegible]	[illegible]	[illegible]			65	[illegible]	33		-	-	-	[illegible]
[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	-	.	.	-	[illegible]
Lympne	[illegible]	[illegible]	[illegible]	[illegible]	65	[illegible]	31	-	.	.	-	9 3
Scilly	[illegible]	[illegible]	[illegible]	[illegible]	65	51	.	-	.	.	.	8 [illegible]
Falmouth	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	56	52	-	[illegible]	.	-	6 7
Plymouth	[illegible]	[illegible]	[illegible]	[illegible]	67	53	[illegible]	-	.	.	-	7 6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	57	.	-	.	.	-	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	53	[illegible]	-	.	.	-	7 [illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	66	56	.	.	-	.	-	
Jersey	b	bc	b	bc	71	46	.	-	.	.	.	6 5

ISOBARS 1st OCTOBER [illegible]

POSITION NUMBERS



Temperature reported from Channel and Coastal Stations

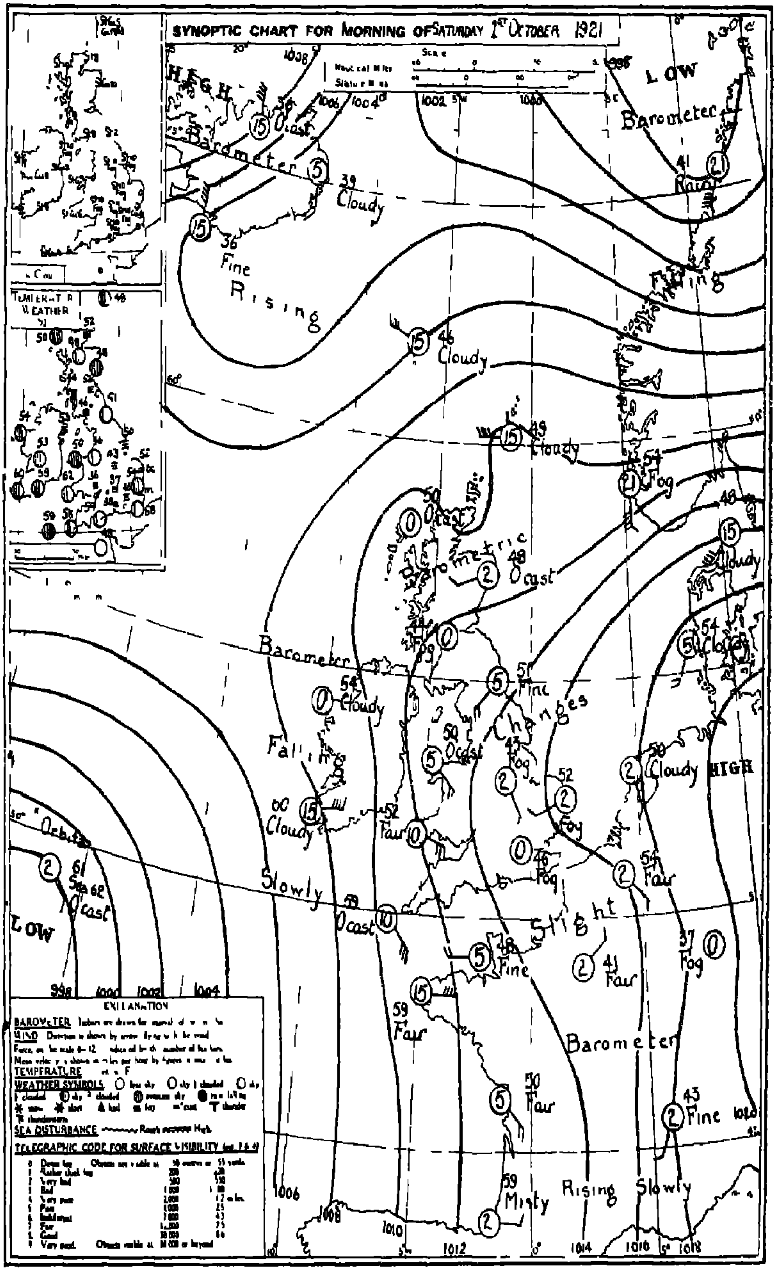
Station Number	3	[illegible]	[illegible]	6
Date	[illegible]	[illegible]	[illegible]	[illegible]
Time GMT	[illegible]	[illegible]	[illegible]	[illegible]
Sea °F	56	62	61	60
Air °F	58	63	[illegible]	60

GENERAL INFERENCE

Pressure is highest over Central Europe but is rising again in Iceland while a depression North of the Azores is growing deeper. Fair weather is probable over the British Isles generally for the next few days with mist or fog at night inland.

District	Forecasts for the 24 hours commencing 15 h GMT Saturday 1st. October 1921.	Further Outlook
1 S.E. England 2 E. England 3 E. Midlands 4 W. Midlands 5 S.W. England 6 South Wales 7 North Wales 8 N.W. England 9 N. Midlands 10 N.E. England	Light to moderate South Easterly winds; fine; mist or fog inland at night and in the morning; moderate temperature, with ground frost locally at night.	There is at present no indication of any break in the fair spell over the Southern half of the Kingdom and the outlook for the extreme North and North-Western districts is for fairer weather than of late.
11 E. Scotland 12 S.W. Scotland 13 Isle of Man 14 N & N.W. Scotland 15 Hebrides	Light indefinite breezes; fair, mist or fog at night; moderate temperature.	
16 Orkneys and Shetlands	Moderate W. to NW. winds; cloudy, some showers; visibility fair to good; rather cold.	
17 N.W. Ireland 18 N.E. Ireland	Light to moderate South Easterly to Easterly winds; fair; mist or fog at night; moderate temperature.	
19 S.E. Ireland 20 S.W. Ireland	Moderate South Easterly winds; cloudy; visibility fair to good; moderate temperature.	

Meteorological Office, Air Ministry, Kingsway, London, W.C.2 — Forecasts issued at — C. C. SIMPSON F.R.S., Director



SYNOPTIC CHART FOR MORNING OF SATURDAY 1ST OCTOBER 1921
HIGH
LOW
Barometer
Rising
Falling
Barometric Changes
Barometer Falling Slowly
Slight
Barometer Rising Slowly
Cloudy
O'cast
Fine
Fog
Fair
Rain
Misty
998
1000
1002
1004
1006
1008
1010
1012
1014
1016
1018
EXPLANATION
BAROMETER
WIND
TEMPERATURE
WEATHER SYMBOLS
SEA DISTURBANCE
TELEGRAPHIC CODE FOR SURFACE VISIBILITY
TEMPERATURE
WEATHER

AIR MINISTRY.

DAILY WEATHER REPORT OF THE METEOROLOGICAL OFFICE, LONDON

 BRITISH SECTION Saturday, 1st October 1921 No 274

Observations at 0100 G.M.T. 1st

Stations	Barom at M.S.L. mb	Change in 3 Hours	Wind Direc	Wind Force 0-12	Weather	Temp. °F	Humidity %	Visibility 0-9	Height of Low Cloud Feet	Cloud Low Form	Cloud Low Amt 0-10	Cloud Upper Form	Cloud Total Amt 0-10	Sea 0-9
Lerwick	009 1	+3	SW	3	or r	54	97	6		Nb	10		10	.
Stornoway	1010 .	0	S	1	o	.	.	6	.	.	.	.	.	.
Wick	1009 6	0	WSW	2	bc	50	97	8			0	C St	4	.
Castlebay	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nairn	.	.	.	.	.		.	.	.	.	.	.	.	.
Aberdeen	.	.	.	.		.		.	.		.	.	.	.
Malin Head														.
Renfrew	019	0		0	ffb	42	97	3	-		0	-	0	.
Leith (Inchkeith)	.	.	.	.	.	.		.	.		.	.	.	.
Eskdalemuir	037	-1	-	0	mb	44	92	4	500	St Cu	2		2	.
Tynemouth	032	-1	SW	2	b	50	92	7			0		0	.
Blacksod Point	004	-2		0	bc	57	97	7	1500	Cu	4		4	
Donaghadee	.	.	.	.		.		.	.		.	.	.	.
Birr Castle	.	.	.		.		.	.	.		.	.	.	.
Baldonnell	1012 2	0	-	9	b	52	92	1	-		0	A St	2	
Holyhead	1012 9	0	SSW	4	b	x	x	8			0		0	
Liverpool (Bidston)	.	.	.	.			.	.	.			.	.	
Manchester (Alex Pk.)	.	.	.	.				.		.	.			
Howden	1016 8	b	S'E	2	b	46	97	5	4000	St	2		2	.
Spurn Head	1015 6	-1	S	4	b	54	75	7			0		0	
Nottingham	.						.	.	.	.		.	.	
Cranwell	1016 5	-1	SW	3	mb	42	97	.			0		0	
Gorleston	1017 2	-1	[illegible]	4	b	57	85	8			0		0	
Pulham	1016 2	1	C	1	mb	40	97	4			0		0	-
Felixstowe														.
Valentia (Cahirciveen)	1008 5	-1	ESE	2	bc	61	65	5	-	St	4	-	4	.
Roches Point		.		.	.		.	.	.	.	.	.	.	.
Pembroke (Milford Haven)	1013 .	0	ESE	2	b	58	85	7	-		0		0	.
Ross on Wye	.	.				.	.	.	.	.	.	.	.	
Benson	.				.	.	.	.	.	.	.	.	.	.
S. Farnborough	.	.	.				.	.	.	.	.	.	.	.
London (Kew Obsy)	.	.			.		.	.	.	.	-	.	.	
Croydon	1016 4	-1	S	1	b.	48	92	6	-		0	-	0	
Clacton on Sea	.	.		.			.		.	.	.		.	
Shoeburyness	.	.				.	.	.		.	.			
Grain	.	.					.	.						
Lympne	1015 6	0	C	2	b	53	97	7		-	0		0	
Scilly (St. Mary's)	1010 0	.	ESE	3	c	58	92	7	1000	St Cu	8		8	
Falmouth														
Plymouth	019	0		0	b	54	92	8			0		0	
Portland Bill	014 9	0	E	4	b	59	95	1			0	C St	2	.
Calshot	1014 8	-	ESE	.	mb	72	85	6			0	C	1	.
Dungeness	15 2	-1	S	3	b	59	85	5	-		0		0	
Jersey (Tb) Guernsey (Tb)	1015 8	0	ESE	2	b.	59	75	7			0		0	.

Observations at 0700 G.M.T. 1st

Stations	Barom at M.S.L. mb	Change in 3 Hours	Wind Direc	Wind Force 0-12	Weather	Temp. °F	Humidity %	Visibility 0-9	Height of Low Cloud Feet	Cloud Low Form	Cloud Low Amt 0-10	Cloud Upper Form	Cloud Total Amt 0-10	Sea 0-9
Lerwick	1010 5	0	W	4	c-	49	92	7	-	St Cu	8		9	3
Stornoway	1010 5	+1		0	o	50	97	6	800	St	10	-	10	0
Wick	1009 8	+1	WNW	1	mc	51	92	5	450	St	8		8	0
Castlebay														
Nairn	1010 6	-		0	bc	48	92	8	1500	St	2	A Cu	3	.
Aberdeen	1011 8	+1	W's	1	o+	48	92	5	4000	St Cu	10		10	0
Malin Head														
Renfrew	1012 5	0		0	fb	44	97	1			0	C St	3	.
Leith (Inchkeith)	1011 1	0	W	1	mbc	52	92	4		St Cu	6		6	1
Eskdalemuir	1013 4	0		0	mc-	46	97	5	800	St	8		8	.
Tynemouth	1013 2	0	SW	2	bc	5	92	4	1500	St	2	C Cu	4	2
Blacksod Point	1008 4	-2	-	0	c-	54	92	7	1500	St	5	A Cu	9	1
Donaghadee	1012 2	0		0	fc+	53	97	2	1500	St	.		10	0
Birr Castle	1009 6		SSW	1	c+	53	92	7	1500	Cu	8		8	.
Baldonnell	1011 7	0		0	bc	41	92	7	3750	St Cu	2	C	4	.
Holyhead	1012 2	0	SE	2	o	50	86	9	1500	St Cu	7	A St	9	1
Liverpool (Bidston)	1012 9	-1	SE	2	[illegible]	46	85	4	5750	St	1	C St	3	0
Manchester (Alex Pk.)	1014 2	2	ESE	1	fbc-	43	97	2			0	A St	4	.
Howden	1016 3	0	SSE	1	FFo	43	97	1	800	St	10		10	.
Spurn Head	1014 2	1	S	3	Fo	50	92	1	<150	St	10		10	2
Nottingham	1015 1	.	SE	1	FFo	43	97	0	225	St	10		10	.
Cranwell	1015 4	0	SSE	1	FFo	42	97	1	<150	St	10		10	.
Gorleston	1016 6	1	WSW	1	fbc	52	97	3	-		0	C Cu	5	1
Pulham	1015 3	-1		0	fmbc	37	97	4			0	C St	6	.
Felixstowe	1016 3	0	-	0	fmc	50	97	4			0	C St	7	1
Valentia (Cahirciveen)	1006 1	-2	ENE	4	c	60	65	8	4000	Cu	5	A St	7	1
Roches Point	1010 3	1	SE	4	c-	59	92	6	2500	St	4	A Cu	8	3
Pembroke (Milford Haven)	1012 0	-1	ESE	3	bc+	52	92	6	4000	St Cu	6		6	3
Ross on Wye	1014 8	-1	S	1	Fo-	36	97	.	<150	St	10		10	.
Benson	1015 9	0	-	0	FFb	37	97	0			0	-	0	.
S. Farnborough	1014 9	0	-	0	FFo	38	97	1	<150	St	10	-	10	.
London (Kew Obsy)	1015 0	0		0	FFo	46	97	0	<150	St	10		0	.
Croydon	1016 8	0		0	FFbc	41	97	0	-		0	A Cu	4	.
Clacton on Sea	1016 0	-1	E	2	mc-	5	92	5			0	C	7	0
Shoeburyness	1015 1	0		0	fbc	43	92	2	1250	Cu	6		6	.
Grain	1015 5	-1		0	FFo	43	97	0	<150	St	10		10	0
Lympne	1014 9	0	SE	2	bc-	51	92	6	-		0	A Cu	4	.
Scilly (St. Mary's)	1009 2	-1	SE	3	o	54	97	8	4000	St Cu	8	C Cu	9	4
Falmouth	1011 4	-1	ESE	3	bc	58	92	5	-	-	0	A Cu	5	.
Plymouth	1012 1	0	E	1	b	55	92	7			0	C	2	0
Portland Bill	1013 3	-2	E	4	b	59	85	7			0	C Cu	3	3
Calshot	1009 4	0	ENE	1	mc	54	97	5	1500	-	1	C	10	0
Dungeness	1015 2	0	SE	2	b-	58	85	7			0	C Cu	-	2
Jersey (Tb) Guernsey (Tb)	1013 2	0	W	7	b	48	85	8			0		0	0

WEATHER, TEMPERATURE, RAINFALL AND SUNSHINE AT HEALTH RESORTS FOR 30th Sept

Stations	Weather Forenoon	Weather Afternoon	Temperature Max Day 30th	Temperature Min Night 29th	Rainfall Night 29th-30th mm	Rainfall Day 30th mm	Sunshine Sunrise to 17h 30th hr	Sunshine 17h to Sunset 29th hr
Banff	o	o	59	47	-	-	0 0	0 8
Montrose	c	c	58	50	-	-	1 3	0 0
Llandudno	bc	bc c	67	48	-	-	6 5	8 2
Colwyn Bay	b	b	68	48	-	-	9 2	9 6
Rhyl	bc	bc	67	46	-	-	6 4	8 0
Southport	w c bc	b bc	64	49	-	-	7 1	4 0
Blackpool	mc	bc	64	50	-	-	5 6	3 0
Harrogate								
Skegness	o c	bc	64	48		-	5 9	7 0
Aberystwyth	o c b	b bc	69	50	-		8 0	10 0
Bath	b	b bco	67	42	-	-	5 6	9 2
Leamington Spa	b	b	66	42	-	-	5 6	7 9
Lowestoft	o c bc	bc	61	54	-	-	6 5	4 2
Felixstowe	bc	bc	62	52	-	-	6 2	4 0
Southend	c bc	bc	65	54	-	-	7 7	5 3

Stations	Weather Forenoon	Weather Afternoon	Temperature Max Day 30th	Temperature Min Night 29th	Rainfall Night 29th-30th mm	Rainfall Day 30th mm	Sunshine Sunrise to 17h 30th hr	Sunshine 17h to Sunset 29th hr
Paignton	w bc	bc c	66	52	-	-	5 1	7 9
Ilfracombe	c bc c	c bc	68	53	-		7 0	10 4
Bude	Wb	b	71	41	-	-	8 1	10 0
Penzance	c bc	bc	64	55	-	-	6 0	9 3
Torquay	Wb bc	bc c	66	55	-	-	4 2	9 5
Weymouth	bc	bc c	69	52	-	-	5 2	10 6
Bournemouth	b bc	c	67	46	-	-	6 0	10 5
Portsmouth (Southsea)	b	b	65	50	-		8 9	10 4
Worthing	b	b	64	50		-	9 0	10 7
Brighton								
Eastbourne	bc	bc	64	50	-	-	9 6	10 3
Hastings	b	b	63	53	-	-	9 5	10 2
Folkestone	b	b	64	52	-	-	8 4	9 6
Tunbridge Wells	b	b bc	57	48	-	-	8 2	8 5
Ramsgate								
Margate	c b	b	64	56	-	-	9 7	9 4
Deal	b	b	64	56	-	-	9 0	6 9

. Information for these columns not usually received † Trace = rain has fallen but amount less than 0.1 mm § For code see page 3 ‡ See footnote page 1

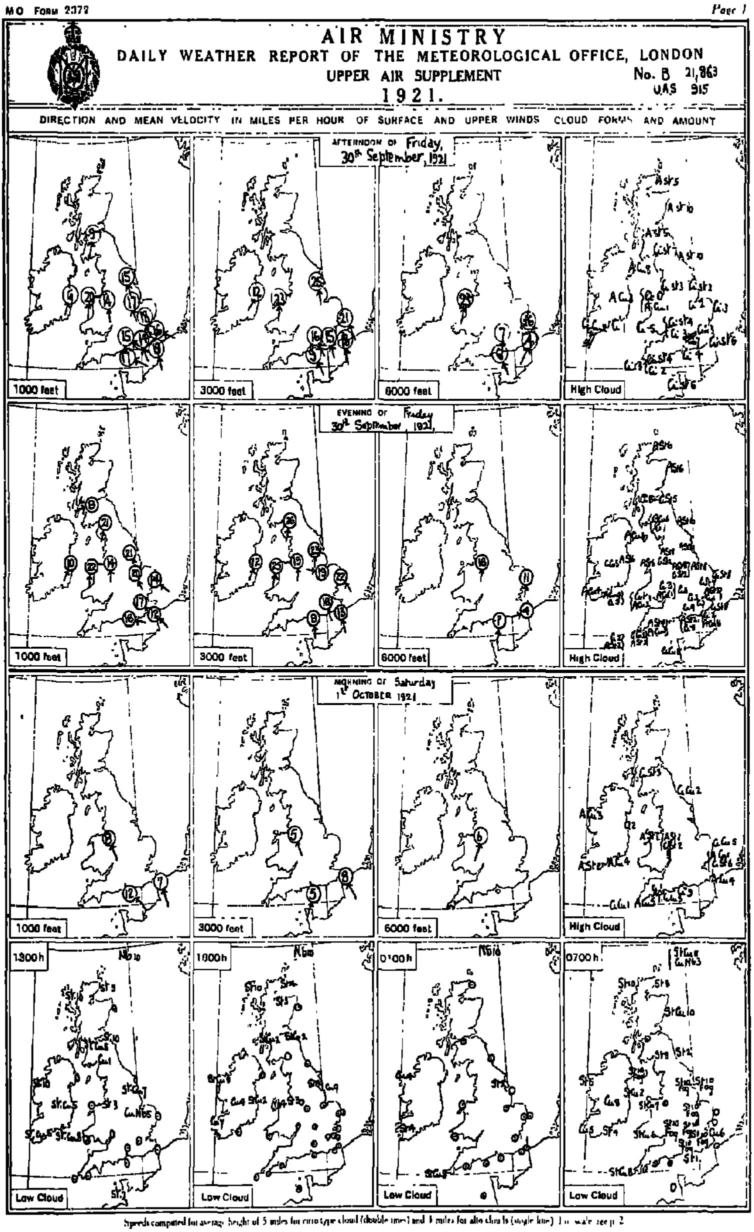


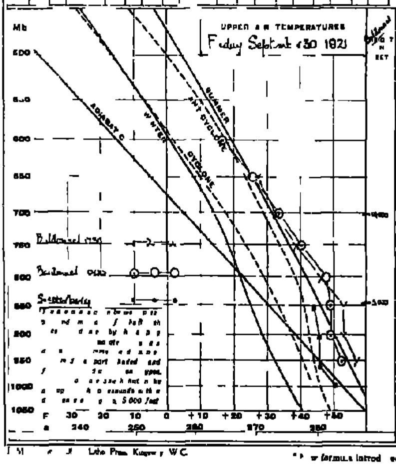
FIG. 5.—Reduced facsimile of the Daily Weather Report (Upper Air Supplement) of October 1, 1921.

DIRECTION AND MEAN VELOCITY IN MILES PER HOUR OF SURFACE AND UPPER WINDS

Height	Renfrew D	S	Baldonnel D	S	Didsbury D	S	Holyhead D	S	Howden D	S	Cranwell D	S	Pulham D	S	Felixstowe D	S	[illegible] D	S	S Farnborough D	S	Gr… D	S	Lympne D	S	Shoeburyness D	S	Calshot D	S
Time	1?00		1200		1200		1100		1200		1200		1100		1200		1200		1100		1300		1200		1200		1200	
Surface	75	5	165	5	40	13	180	15	355	21	180	12	140	12	110	14	85	14	55	10	95	17	100	10	105	15	120	12
1000	95	9	195	6	170	4	160	20	165	15	170	17	130	18	115	16	130	14	115	15	120	19	130	19	110	22	110	17
2000	200	2	200	0			180	22	165	16	170	18	90	14	125	21	140	17	125	17	135	21	145	21	120	26	220	16
3000			205	12			160	23	170	25					130	21	150	16	155	16	140	32	160	18	140	21	135	9
4000							150	24	170	21					125	22	185	8	155	11	185	29	155	14	150	20	155	0
5000							205	20							150	15			175	6	140	40	175	8			160	8
6000							190	23							135	16			195	7	160	37	215	4			165	6
8000																			280	5	160 (7000)	34	240	3			205	5
10000																			280	8			250	6			250	6
12000																			295 (3000)	13			260	13			270 (1?000)	6
14000																							280	18				
16000																							275	25				
																							265 (30 000)	25				

Height	Renfrew D	S	[illegible] D	S	Baldonnel D	S	Didsbury D	S	Holyhead D	S	Howden D	S	Cranwell D	S	Pulham D	S	Croydon D	S	Lympne D	S	Calshot D	S
Time	1800		1700		1700		1800		1100		1900		1700		1500		1700		1100		1700	
Surface	175	3	20	7	Calm		150	12	170	10	160	10	155	18	120	3	120	3	75	4	110	8
1000	240	9	210	[illegible]	21	0	170	14	190	22	165	21	155	20	130	4	135	17	130	12	115	18
2000	245	12	205	24	205	0	110	16	180	22	180	23	165	19	130	17	155	1?	140	14	60	12
3000			20?	[illegible]	215	12	160	19	205	25	185	23	275	18	140	22	100	16	160	13	70	9
4000							215	17	2?5	[illegible]					160	22	150	6	160	8	160	5
5000							2?5	17	230	21					190	17	165	7	185	3	190	9
6000							205	16							205	11			260	4	190	
8000							215	22							210	11			265	6	170	6
10000							[illegible]	14							225	11			235	4		
12000															210	12						

Height	Didsbury D	S	Lympne D	S	Calshot D	S
Time	0600		0600		0600	
Surface	5	5	0	4	65	5
1000	6		160	7	145	2
2000	55	6	145	7	190	9
3000	5	5	150	8	100	5
4000	195	13	15	6	160	5
5000	85	1	115	4		
6000	20	6				
8000	75	8				
10000	16					



All [illegible] by single theodolite pilot balloon ascents except where otherwise specified.
d = double theodolite ascent
[illegible] balloon observation
[illegible] shell burst observation (1 [illegible])
(2 [illegible])

CLOUD MOVEMENTS

- no speed given
- 0-5 m.p.h.
- 5-15
- 15-25
- 25-35 m.p.h.
- 35-45
- 45-55
- 55-65

O [illegible] the direction of cloud

UPPER AIR TEMPERATURES AND HUMIDITIES*

Station	mb	Height ft	Temp Dry	Temp Wet	Humidity	Station	mb	Height ft	Temp Dry	Temp Wet	Humidity
Baldonnel 0600		MSL				Baldonnel 1730		MSL Surface	65		
		280	57	54	83			800	58	55	79
		800	55	52	82		950	1890	57	52	73
	950	1800	52	49	81		900	3170	52	46	64
	900	3270	49	46	46		850	4730	52	47	72
	850	4600	48	[illegible]			800	6570	46	44	87
	800	6470	46	[illegible]	[illegible]		750	8460	38	35	69
	750	8100	40	[illegible]	[illegible]		700	9820	32	28	64
	700	[illegible]	[illegible]	[illegible]	[illegible]		650	[illegible]	26	26	80
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						

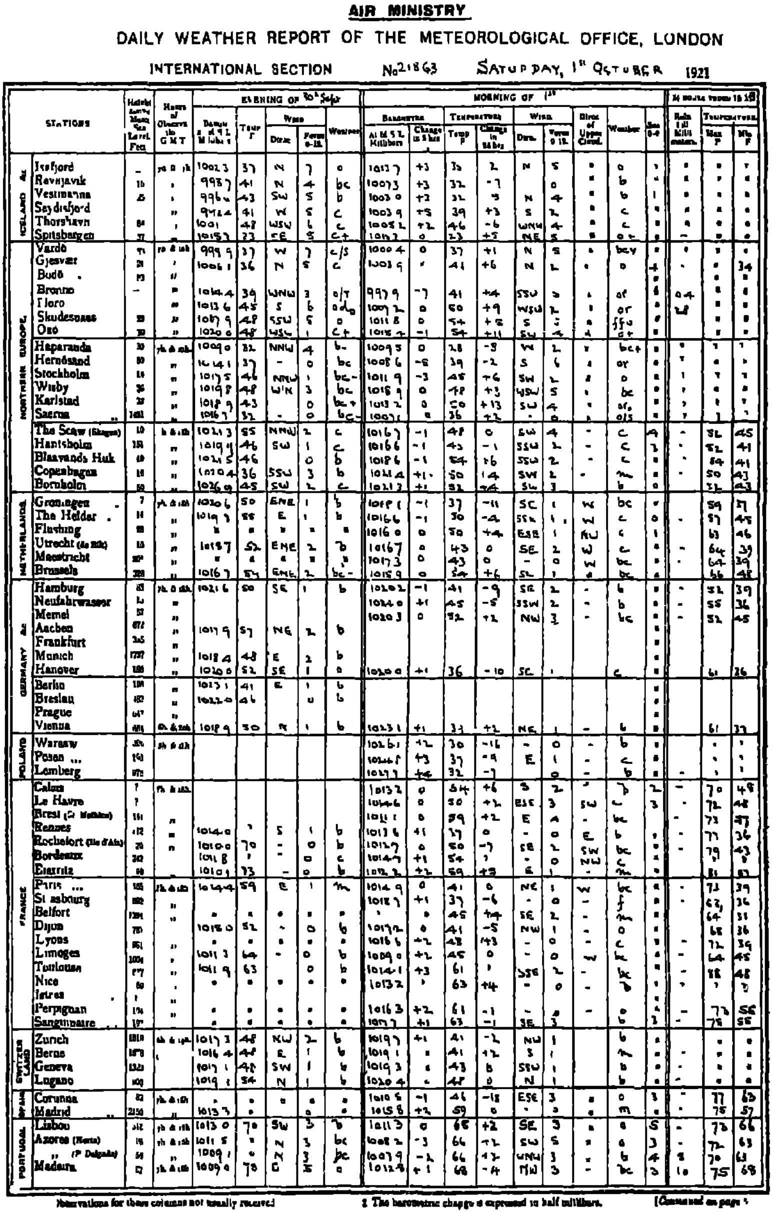
Station	Time	Height	Temp Dry	Temp Wet	[illegible]	Station	Height	Dry	Wet		Station	Pressure	Height	Temp Dry	Temp Wet	Rel Hum
		F	F	F			F	F	°F			mb	F	F	F	

Meteorological Office Air Ministry Kingsway London W.C.2.

G. C. SIMPSON F.R.S. Director

[illegible] Litho Press Kingsway W.C.

* New formula introduced from September 19th 1921. See introduction



AIR MINISTRY

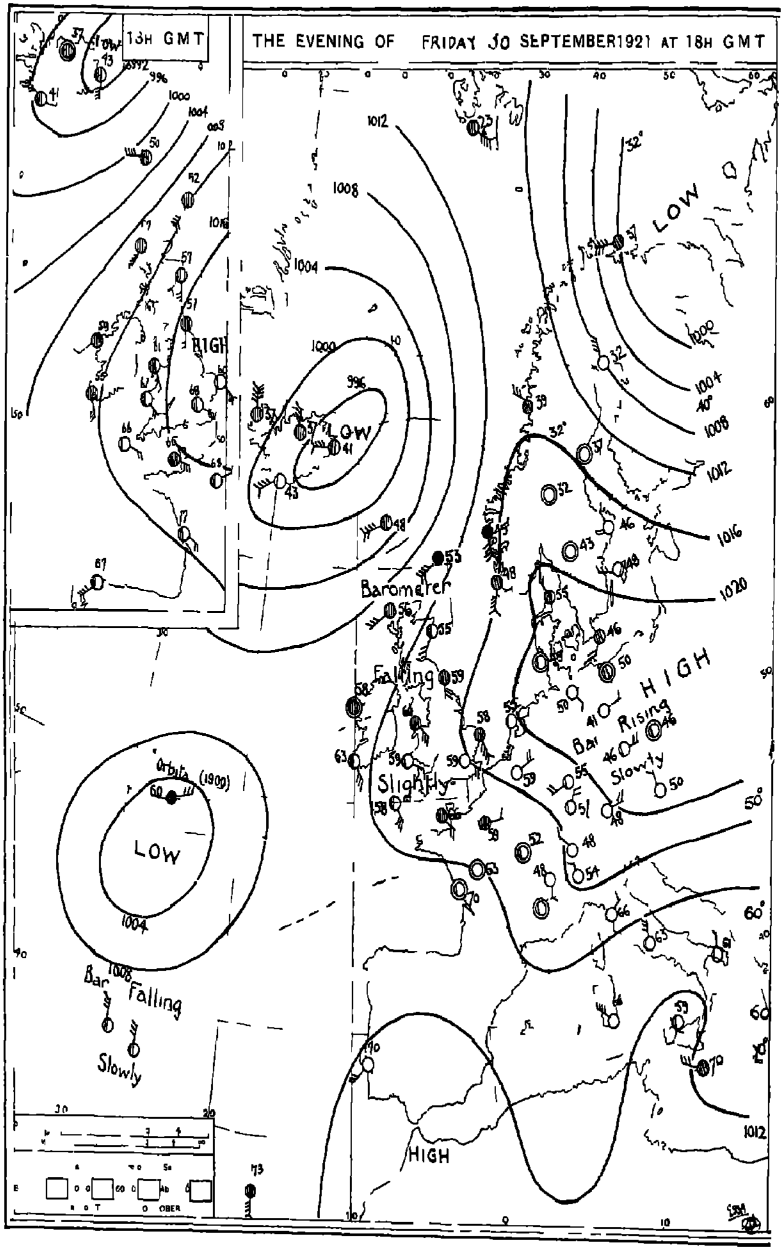
DAILY WEATHER REPORT OF THE METEOROLOGICAL OFFICE, LONDON

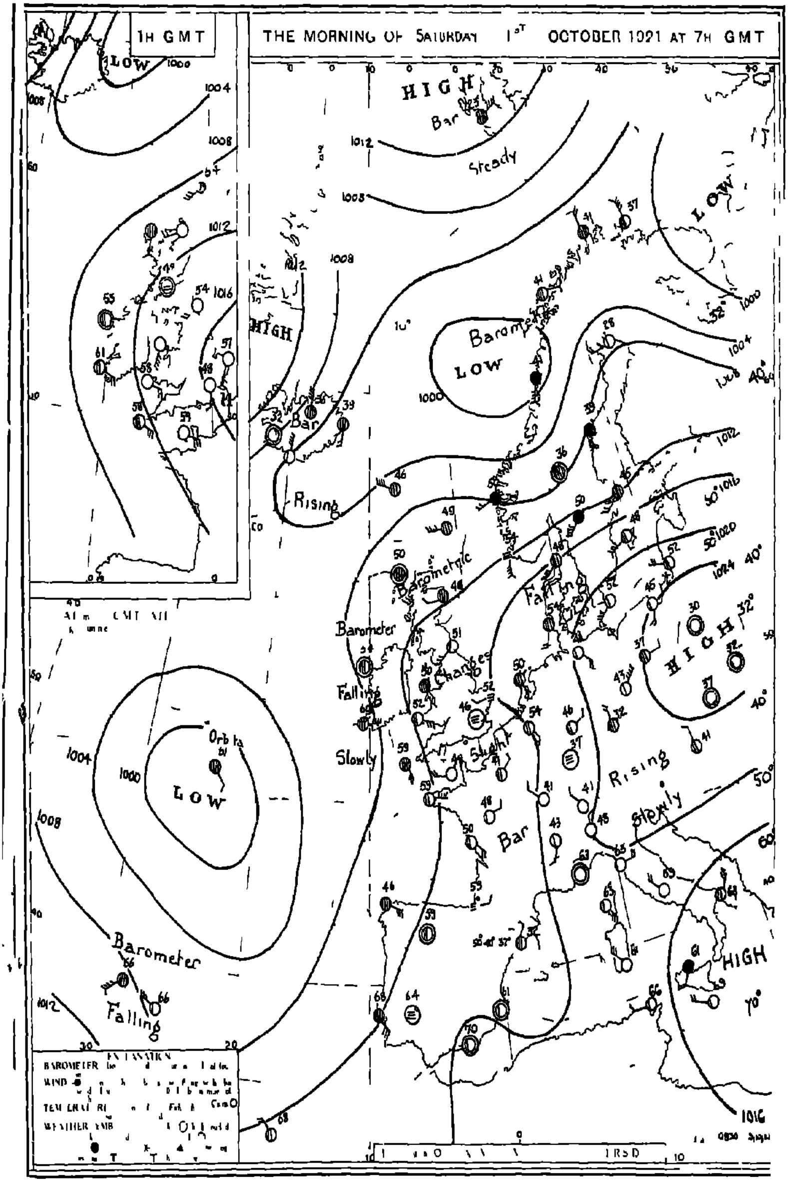
INTERNATIONAL SECTION No. 21863 SATURDAY, 1st OCTOBER 1921

	Stations	Height above Mean Sea Level Feet	Hours of Observ. GMT	Evening of 30th Sept.: Barom. at MSL Millibars	Evening: Temp. F	Evening: Wind Dir.	Evening: Wind Force 0-12	Evening: Weather	Morning of 1st: Barom. at MSL Millibars	Morning: Barom. Change	Morning: Temp. F	Morning: Temp. Change in 24 hrs	Morning: Wind Dir.	Morning: Wind Force 0-12	Direc. of Upper Cloud	Weather	Sea 0-9	24 hours: Rain Millimetres	24 hours: Max. F	24 hours: Min. F
ICELAND &c.	Isafjord	–	[illegible]	1002 3	37	N	7	o	1013 7	+3	35	2	N	5	.	o	.	.	.	.
	Reykjavik	16	„	998 7	41	N	4	bc	1007 3	+3	32	-7		o	.	b	.	.	.	.
	Vestmanna	[illegible]	„	996 4	43	SW	5	b	1003 0	+2	32	-9	N	4	.	b	1	.	.	.
	Seydisfjord		„	992 4	41	W	5	c	1003 9	+5	39	+3	S	2	.	c	.	.	.	.
	Thorshavn	84	„	1001	48	WSW	6	c	1005 2	+2	46	-6	WNW	4	.	c	.	.	.	.
	Spitsbergen	37		1015 7	23	SE	5	c+	1011 7	o	23	+5	NE	5	.	o+	.	–	.	.
NORTHERN EUROPE	Vardö	[illegible]	[illegible]	999 9	37	W	7	c/s	1000 4	0	37	+1	N	5	.	bcy	.	.	.	.
	Gjesvær	[illegible]	„	1006 1	36	N	5	c	1003 9	.	41	+6	N	2	.	o	4	.	.	34
	Bodö	[illegible]	„														.		.	.
	Bronno	–	„	1014 4	39	WNW	3	o/r	997 9	-7	41	+4	SSW	5	.	of	6	0 4	.	.
	Floro		„	1013 6	45	S	6	odo	1009 2	0	50	+9	WSW	2	.	or	.	28	.	.
	Skudesnaes	[illegible]	„	1017 9	48	SSW	5	o	1011 8	0	54	+5	S	[illegible]	.	ffo	.		.	.
	Oxö	[illegible]	„	1020 0	48	WSW	1	c+	1015 4	-1	54	+11	SW	4	4	o+	.		.	.
	Haparanda	30	[illegible]	1009 0	32	NNW	4	b-	1009 5	0	28	-5	W	2	.	bc+	.	.	.	.
	Hernösand	[illegible]	„	1014 1	37	–	0	bc	1008 6	-6	39	-2	S	6	.	or	.	.	.	.
	Stockholm	[illegible]	„	1017 5	46	NNW	1	bc-	1011 9	-3	45	+6	SW	2	.	o	.	1	.	.
	Wisby	36	„	1019 8	48	WNW	3	bc	1015 9	0	48	+3	WSW	5	.	bc	.	.	.	.
	Karlstad	[illegible]	„	1018 9	43		0	bc+	1013 2	0	50	+13	SW	4	.	of	.	.	.	.
	Saerna	1461	„	1016 7	32	–	0	bc-	1007 1	.	36	+2	–	o	.	o/s	.	.	1	.
	The Skaw (Skagen)	10	[illegible]	1021 3	55	NNW	2	c	1016 7	-1	48	0	SW	4	–	c	4	–	52	45
	Hantsholm	[illegible]	„	1019 4	46	SW	1	c	1016 6	-1	43	-1	SSW	2	–	c	3	.	52	41
	Blaavands Huk	[illegible]	„	1021 5	46		0	b	1018 6	-1	54	+6	SSW	2	–	c	.	.	54	41
	Copenhagen	[illegible]	„	1020 4	36	SSW	3	b	1011 4	+1	50	14	SW	2	–	m	.	–	50	43
	Bornholm	[illegible]	„	1026 9	45	SW	2	c	1021 3	+1	52	+4	SW	3		b	o		52	43
NETHERLANDS	Groningen	7	[illegible]	1020 6	50	ENE	1	b	1018 1	-1	37	-11	SE	1	W	bc	.		59	37
	The Helder	[illegible]	„	1019 9	55	E	1	b	1016 6	-1	50	-4	SSE	1	W	c	o	–	57	45
	Flushing	[illegible]	„	.	.	.	.	.	1016 0	0	50	+4	ESE	1	NW	c	1		63	46
	Utrecht (de Bilt)	[illegible]	„	1018 7	52	ENE	2	b	1016 7	0	43	0	SE	2	W	c	.	–	64	39
	Maestricht	[illegible]	„	.	.	.	.	.	1017 3	0	43	0	–	0	W	bc	.	.	64	39
	Brussels	[illegible]	„	1016 7	54	ENE	2	bc-	1015 9	0	54	+6	SE	1	.	bc	.		66	48
GERMANY &c.	Hamburg	[illegible]	[illegible]	1021 6	50	SE	1	b	1020 2	-1	41	-9	SE	2	–	b	.	–	52	39
	Neufahrwasser	[illegible]	„						1024 0	+1	45	-5	SSW	2	–	b	.	–	55	36
	Memel	[illegible]	„						1020 3	0	52	+2	NW	3	–	bc	.	–	52	45
	Aachen	[illegible]	„	1017 9	57	NE	2	b									.			
	Frankfurt	[illegible]	„														.			
	Munich	[illegible]	„	1018 4	48	E	2	b									.			
	Hanover	[illegible]	„	1020 6	52	SE	1	o	1020 0	+1	36	-10	SE	1		c	.		61	36
	Berlin	[illegible]	„	1013 1	41	E	1	b									.			
	Breslau	[illegible]	„	1022 0	46		0	b									.			
	Prague	[illegible]	„														.			
	Vienna	[illegible]	[illegible]	1018 9	50	N	1	b	1023 1	+1	34	+2	NE	1	–	b	.		61	37
POLAND	Warsaw	[illegible]	[illegible]						1026 1	+2	30	-16	–	0	–	b	.		.	.
	Posen	[illegible]							1024 8	+3	37	-9	E	1	–	c	.		.	.
	Lemberg	[illegible]							1027 7	+4	32	-7		0	–	b	.	–	.	.
FRANCE	Calais	7	[illegible]						1013 2	0	54	+6	S	2	–	b	2	–	70	49
	Le Havre	7							1014 6	0	50	+2	ESE	3	SW	–	3	.	72	48
	Brest (St Mathieu)	[illegible]	„						1011 1	0	59	+2	E	4	.	bc		–	73	57
	Rennes	[illegible]	„	1014 0	.	S	1	b	1013 6	+1	37	0	–	0	E	b	.	–	77	36
	Rochefort (Ile d'Aix)	[illegible]	„	1010 0	70	–	0	b	1012 7	0	50	-7	SE	2	SW	bc	.	–	79	43
	Bordeaux	[illegible]		1011 8	.	–	0	c	1014 7	+1	54	.	.	0	NW	c	.			
	Biarritz	[illegible]		1010 1	73	–	0	b	1012 2	+2	59	+5	E	1	.	m	.		[illegible]	[illegible]
	Paris	[illegible]	[illegible]	1014 4	59	E	1	m	1014 9	0	41	0	NE	1	W	bc	.	–	73	39
	Strasbourg	[illegible]	„						1018 7	+1	37	-6	.	0	–	f	.	.	63	36
	Belfort	[illegible]	„	.	.	.	.	.	.	.	45	+4	SE	2	–	m	.		64	31
	Dijon	[illegible]		1015 0	52	–	0	b	1017 2	0	41	-5	NW	1	–	o	.		68	36
	Lyons	[illegible]	„	.	.	.	.	.	1016 6	+2	48	+3	–	0	–	c	.	–	72	39
	Limoges	[illegible]	„	1011 3	64	–	0	b	1009 0	+2	45	0	–	0	W	bc	.	–	64	45
	Toulouse	[illegible]	„	1011 9	63		0	b	1014 1	+3	61	.	SSE	2	–	bc	.	–	[illegible]	48
	Nice	[illegible]	.	.	.	.	.	.	1013 2	.	63	+4	–	0	–	b	.	.	.	.
	Istres	[illegible]	„														.			
	Perpignan	[illegible]	„	.	.	.	.	.	1016 3	+2	61	-1	–	.	–	o	4	–	73	56
	Sanguinaire	[illegible]		.	.	.	.	.	1017 7	+1	63	-1	SE	3		b	3	–	75	55
SWITZERLAND	Zurich	[illegible]	[illegible]	1017 3	48	NW	2	b	1019 7	+1	41	-2	NW	1		b	.		.	.
	Berne	[illegible]		1016 4	48	E	1	b	1019 1	.	41	+2	S	1		m	.	–	.	.
	Geneva	[illegible]		1017 1	48	SW	1	b	1019 3	.	43	6	SSW	1		b	.	–	.	.
	Lugano	[illegible]		1019 1	54	N	1	b	1020 4	.	48	0	N	1		b	.	–	.	.
SPAIN	Corunna	[illegible]	[illegible]	.	.	.	.	.	1010 5	-1	46	-18	ESE	3	.	o	3	–	77	63
	Madrid	2150	„	1013 7	.		.	.	1015 8	+2	59	0	.	3	.	m	.	.	75	57
PORTUGAL	Lisbon	312	[illegible]	1013 0	70	SW	3	b	1011 3	0	68	+2	SE	3	.	o	S	–	73	66
	Azores (Horta)	[illegible]	[illegible]	1011 5	.	N	3	bc	1008 2	-3	66	+2	SW	5	.	o	3	–	72	63
	„ (P. Delgada)	[illegible]	„	1009 1	.	N	3	bc	1007 9	-2	66	+2	WNW	3	.	b	4	5	70	63
	Madeira	[illegible]	[illegible]	1009 0	78	[illegible]	[illegible]	o	1012 9	+1	68	-4	NW	3	–	bc	3	10	75	68

Observations for these columns not usually received. ‡ The barometric change is expressed in half millibars. [Continued on page ?

FIG. 6.— Reduced facsimile of the Daily Weather Report (International Section) of October 1, 1921.


13H GMT
THE EVENING OF FRIDAY 30 SEPTEMBER 1921 AT 18H GMT
LOW
HIGH
LOW
LOW
HIGH
LOW
HIGH
Barometer Falling Slightly
Bar Rising Slowly
Orbita (1909)
Bar Falling Slowly
1012
1008
1004
1000
996
1016
1020


1H GMT
THE MORNING OF SATURDAY 1ST OCTOBER 1921 AT 7H GMT
HIGH
LOW
Bar Steady
Barometer LOW
HIGH
Bar Rising
Barometric Changes Slight
Barometer Falling Slowly
Falling
Bar Rising Slowly
HIGH
LOW
Barometer Falling
HIGH

AIR MINISTRY.

DAILY WEATHER REPORT OF THE METEOROLOGICAL OFFICE, LONDON

INTERNATIONAL SECTION No. [illegible] Saturday, 1st October 1921

Stations	Height above M.S.L. Feet	Hour of Observation G.M.T.	Barom. M.S.L. Millibars	Temp.	Wind Dir.	Wind Force 0-12	Weather	Barom. Millibars	Change	Temp.	Change	Wind Dir.	Wind Force	Direc. of upper Cloud	Visibility	Sea	Rainfall mm	Max. F	Min. F
Turin	907	7h [illegible]																	
Legnorn			1013 6	66	NE	1	b	1016 2	+	63	+2	E	2		b	5		72	47
Rome	161		1011 0	63	N	3	b	1016 8	0	59	-2	N	2	-	b	0	-	73	54
Taranto			1011 4	61	N	1	b	1014	0	63	+2	NNE	2	NE	bc	3	3	64	61
Cagliari	4		1013	66	NW	1	b	1016 7	0	61	+2	NW	3	-	b	3	-	73	57
Palermo			1012 8	59	SSW	1	b	1016 5	0	61	+2	SSW	5	-	r	2	7	68	57
Gibraltar	3	7h [illegible]																	
Algiers	1??																		
Malta	[illegible]	[illegible]	10 0 2	70	N	3	bc	1014 5	+4	69	+2	NW	7	-	b	2	1	72	67
Athens	351		1012 8	66	-	0	c	1012 0	+1	63	0	NE	3	-	c	0	28	73	55
Candia	[illegible]		10 4 [illegible]	71	NE	1	bc	1015 1	+1	66	-4	-	0	-	b	0		82	63
Limassol	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1013 2	0	75	-2		0	-	b	1		84	61
Alexandria	[illegible]	[illegible]	1012 6	77	NE	1	b	1012 -	-	79	0	-	[illegible]	[illegible]	b	[illegible]	[illegible]	[illegible]	[illegible]
Cairo (Helwan)	[illegible]	-	10 6 3	84	NE	5	b	1012 8	+3	77	-7	W	1	[illegible]	b	[illegible]	-	101	70
Matruh	[illegible]		1026 0	77		0	b	1016 2	[illegible]	77	19	-	0	[illegible]	b	[illegible]	[illegible]	[illegible]	[illegible]

WIRELESS REPORTS FROM THE ATLANTIC

Date and Hour	Ship	Lat.	Long.	Barom.	Wind Dir.	Wind Force	Weather Present	Weather Past	Temp. Air	Temp. Sea	Visibility	Cloud Form	Cloud Total Amt.	Swell Scale No.	Swell Direc.	Rain began
30th 1800	[illegible]	48 16	39 42	1009	[illegible]	3	bcp	b	61	62	-	St Cu	6	0	NE	0630
2400		49 0	[illegible] 18	1002	ENE	3	or	00	60	54	8	A St	10	0	E	[illegible]
1st 0700		49 8	32 6	998	SE	1	o	c	61	62	7	A St	10	1	SE	-

UPPER AIR TEMPERATURES ABROAD

NOTES

UPPER WIND ABROAD

Station	Toulouse		Paris		Bordeaux		Paris		Toulouse		Paris	
Time	13h00 30th		1300 30th		1630 30th		1800 30th		0700 1st		0700 1st	
Height in Feet	Dir. Deg.	Vel. m.p.h.	Dir. Deg.	Vel. m.p.h.	Dir. Deg.	Vel. m.p.h.	Dir. Deg.	Vel. m.p.h.	Dir. Deg.	Vel. m.p.h.	Dir. Deg.	Vel. m.p.h.
13,100							270	4				
[illegible]												
9,840	23	13	68	9	270	9	203	9	360	13	158	27
8,270					-		-		-	-		
6,560	360	1	68	9	248	13	158	9	338	9	135	22
4,920	360	1	68	9	170	9	198	9	315	9	135	18
3,280	360	1	90	22	203	22	113	13	315	9	113	9
1,640	360	1	90	1	113	22	90	13	338	9	135	9

NOTES ON THE WEATHER OF THE 24 HOURS ENDED 7H TO-DAY

The anticyclone still maintained its position with the highest pressure over Central Europe and the barometer was rising again in Iceland. A depression North of the Azores was growing deeper while pressure was diminishing over the British Isles. Fair or fine weather with light winds and some mist or fog prevailed over Central and Southern Europe but rain or sleet fell in Scandinavia with strong squally South to West winds. As much as 28 mm of rain fell at Floro, but small amounts elsewhere, 5 mm at Madeira. Temperature rose to 84° at Limassol, 82° at Candia and 81° at Biarritz but did not greatly exceed 50° in the North, 50° being the maximum at Copenhagen and 52° at Skagen, Hantsholm and Bornholm. The previous night was cold inland, mild on the Coast, the lowest screen readings being 31° at Belfort, 33° at South Farnborough 34° at Gjesvaer and 35° at Ross-on-Wye and Benson

THE DAILY WEATHER REPORT OF THE METEOROLOGICAL OFFICE IN 1921

The changes which have been introduced into the Daily Weather Report since 1910 are many and not altogether easy to follow. The first change was the substitution in 1911 of the "barometric tendency," that is to say, the change of pressure within the three hours preceding the time of observation in lieu of the temperature of the wet-bulb. In 1912 there was a meeting of the International Commission for Weather Telegraphy which proposed other changes in the international code for the exchange of weather messages. The changes were approved at a meeting of the International Meteorological Committee at Rome in 1913, and adopted for the Daily Weather Report on January 1, 1914; and the occasion was utilised to introduce a more effective method of plotting the observations on the map. Under the new arrangement a small circle represented the position of the station, a line drawn up to it, the direction of the wind; the force of the wind on the Beaufort scale was indicated by a corresponding number of feathers to the wind-arrow, a circle surrounding the station's circle indicating calm. The letters, which indicated the state of the sky and weather were omitted from the charts and the state as regards cloudiness indicated by a number of vertical strokes across the circle, one for one-quarter clouded, two for one-half, three for three-quarters, and four for overcast. When it was raining the station's circle was replaced by a smaller black dot; when it was snowing, by a star, and when it was hailing, by a black triangle. When it was foggy three horizontal strokes replaced the circle. The temperature was written in figures. The method of representation was adhered to throughout the war and until after the close of 1918. With April 1, 1919, the practice of having separate sheets for British observations, for observations from overseas, and for observations of the upper air came in, and with it the extension of British observations on clouds and some modifications of the practice of charting, of which the most noticeable is the entry of wind-

velocity in miles per hour within the station-circle. This was called for by the report that in the Navy wind-velocities were always required in miles per hour and that the force on the Beaufort scale had little significance for modern ships.

At the same time the information was expanded to take account of observations every six hours of 100 varieties of present and past weather, the observations of visibility and all the other details which, by a remarkable *tour de force* on the part of the Supreme Council, were embodied in the Treaty of Versailles. It is probably the first occasion on which the course of scientific study of weather has been ordained by direct political action.

The full effect of the changes which have been introduced into the Daily Weather Report since 1910 may be understood by comparing the facsimile reprint of that for Saturday, October 1, 1921 (Figs. 4, 5, 6) with the previous one of Fig. 3.

Page 1 of the British Section (Fig. 4) gives the observations at official British stations at 1300 G.M.T. and 1800 G.M.T. (1 p.m. and 6 p.m.) of the previous day: observations for nine stations within greater London, comprising measures of atmospheric pollution at Richmond and South Kensington, total solar radiation at South Kensington in joules, and its average and maximum rate in milliwatts, the duration of the photographic record of Polaris and of δ Ursæ Minoris at the Royal Observatory, Greenwich, a table of sunrise and sunset at Greenwich, Yarmouth, Wick and Valencia (Ireland), the Beaufort notation for weather, the equivalents of the Beaufort scale of wind-force, and the following:—

Scale for Sea-disturbance at Coast Stations.

0. No swell.	Calm or slight sea.	3. No swell.	Moderate sea.
1. Moderate swell.		4. Moderate swell.	
2. Heavy swell.		5. Heavy swell.	

6. Rather rough sea.
7. Rough sea.
8. Very rough sea.
9. Mountainous sea.

Similar observations are given on the fourth page for 0100 G.M.T. and 0700 G.M.T. (1 a.m. and 7 a.m.). In these observations *pressures* are given in *millibars*; *barometric tendency*, the

change of pressure within the three hours previous to the observation, in *half-millibars* ; *humidity*, the results of the wet and dry bulbs, which had been omitted after 1911, has been restored in the form of relative humidity. Four columns are assigned to the form and amount of cloud, divided into low cloud and high cloud, and an additional column gives the height of low cloud. Sea disturbance comes in as before, with the scale given on page 24. Visibility is given according to the following scale :—

Scale of Visibility.

0. Dense fog. Objects not visible at 50 metres, or 55 yards.
1. Rather thick fog. Objects not visible at 200 metres, or 220 yards.
2. Very bad. Objects not visible at 500 metres, or 550 yards.
3. Bad. Objects not visible at 1,000 metres, or 1,100 yards.
4. Very poor. Objects not visible at 2,000 metres, or 1·2 miles.
5. Poor. Objects not visible at 4,000 metres, or 2·5 miles.
6.[1] Indifferent. Objects not visible at 7,000 metres, or 4·3 miles.
7.[1] Fair. Objects not visible at 12,000 metres, or 7·5 miles.
8.[1] Good. Objects not visible at 30,000 metres, or 18·6 miles.
9.[1] Very good. Objects visible at 30,000 metres, or beyond.

On the fourth page, besides the term-observations at 0100 G.M.T. and 0700 G.M.T. at the official stations, we find the observations at health resorts in their accustomed place.

On the third page is a map of the region of North-Western Europe, extending from the Mediterranean and the Azores to the north of Iceland on the scale of 1 : 10,000,000, the customary scale of the working charts of the office, with two insets representing weather, temperature and cloud over the British Isles. On the second page we have summaries of weather, temperature, rainfall and sunshine for the twenty-four hours preceding 07 G.M.T., and another inset map, which gives the " isallobars " computed after the fashion explained in Chapter XXII., and the

[1] In 1922 the scale for visibility at greater distances was altered and became—

6. Moderate. Objects not visible at 6¼ miles.
7. Good. Objects not visible at 12½ miles.
8. Very good. Objects not visible at 31¼ miles
9. Excellent. Objects visible beyond 31¼ miles.

remaining space is devoted to General Inference, Forecasts and Further Outlook.

In the tabular summary on the second page the details of the weather are expressed by a series of letters of the Beaufort notation (amplified for the purpose) which may run into two dozen instead of the half-dozen, at most, that appeared in 1910. The minimum temperature on the grass is given: rainfall is reported in two separate portions, day-rainfall between 07 G.M.T. and 18 G.M.T. and night-rainfall between 18 G.M.T. and 07 G.M.T. the next morning; two columns are assigned to the times at which the rain is observed to begin. Altogether, sixty-eight columns are now provided for the observations from each station, fifty-six for term-observations and twelve for observations referring to the twenty-four hours, in place of the nineteen columns of 1910, which were made up of fourteen term-columns and five day-columns.

As there are forty-four stations the number of spaces for observations from the British Isles alone works out at only eight short of 3,000. Though all the spaces are not filled and are not expected to be filled there are the additional observations for London and the health resorts to be added, as well as the observations in the Upper-Air Supplement (Fig. 5), so that the amount of material to be mapped is vastly greater than it used to be.

At the same time more detail is expected in the forecasts. The British Isles are now divided into twenty districts instead of twelve and we begin with England S.E. now instead of Scotland N. The new enumeration of the districts is given in Fig. 59. Some advance has also been made in the practice of forecasting, for on September 26, 1921, the further outlook was successfully extended to ten days ahead.

Next to the British Section we may place the Upper-Air Supplement (Fig. 5), which provides space for plotting the results for the winds at various levels up to 14,000 feet obtained by means of pilot-balloons at nineteen stations (more or less) with maps for charting the values at 1,000 feet, 3,000 feet and 6,000 feet, three times in the day—on the morning of the day, and the afternoon

and evening of the previous day—and also for charting low cloud for the four term-hours and the high cloud, for morning and previous afternoon and evening as before. On the second page space is provided for observations of temperature (dry and wet bulb) and relative humidity in the upper air at six stations, and the values are plotted as graphs of height-temperature on a form which always shows the values of the dry adiabatic lapse-rate of temperature and the normal values of the lapse for summer and winter and for cyclone and anticyclone.

Of the four pages of the International Section (Fig. 6) the inner two are devoted to maps on the scale of the chart for 7 a.m. of 1910, namely, $1 : 2 \times 10^7$, but there is no longer a separate chart of temperature and weather. There are charts for 07 G.M.T. of the day of issue and 18 G.M.T. of the previous day, which fill the whole page with the exception of the north-west corner, where an inset gives the observations which are available for 13 G.M.T. and 01 G.M.T. The forms of the charts have been subject to progressive changes, but the final form will be understood from the facsimile report. The area represented is very extensive. It includes Spitsbergen in the north, the Mediterranean and Madeira in the south, the Azores and Greenland in the west and Western Russia in the east.

On the outside pages are the observations from the Continental stations very much in their old form, and on the fourth page space is found for wireless reports from the Atlantic, which run to seventeen columns instead of the eleven of olden days, and also for a table of upper air-temperatures and upper air-winds from abroad.

The areas covered by the new maps are represented on a map of the distribution of pressure and winds over the northern hemisphere in July (Fig. 11).

Radio-telegraphy is now generally used for exchanging the observations between different countries. The number of occasional blanks is at present much larger than it used to be, but gradually the system is being tuned up to the efficiency of the old cables for the purpose of exchanging weather reports and by the

time the process is complete the general distribution to all the offices of Europe will be much improved.

The information which is supplied by the telegraphic reporting stations to the Central Meteorological Office of the Air Ministry in Kingsway is distributed from there by radio-telegraphy for the use of the officers in charge of the meteorological stations at the aerodromes of the Ministry. The reports from foreign stations are also received at the Meteorological Office by radio-telegraphy. Selections from the European reports, together with other information, are sent out by radio-telegraphy from the Eiffel Tower and other stations. British and foreign, to be received by local meteorological establishments and ships.

The facilities for " listening in " for these messages are becoming more and more widespread so that now any reader of this book, who possesses a radio-set, or has a friend in that enviable position, may put into practice the system of forecasting which is its subject. This development brings the material of forecasting to everybody's door or at least to everybody's roof. We are constrained therefore to ask the reader to endure some tedious details which he may amplify at his pleasure by consulting the official papers issued with the express object of putting him in possession of the necessary information: this includes the times at which the various messages are broadcasted, the wave-length and other particulars, as well as the nature of the messages transmitted, and the codes employed. The details of agreement as to the international code will be found in M.O. 248, " Report of the Eleventh Ordinary Meeting of the International Meteorological Committee, London, 1921," Appendix VI., and the following papers based upon the agreement have been issued: M.O. 253, " The New International Code for Meteorological Messages "; M.O. 252, " Particulars of Meteorological Reports issued by Wireless Telegraphy in Great Britain and by the Countries of Europe and North Africa," and M.O. 255, Meteorological Office " Wireless Weather Manual." Here we recapitulate the forms of the various messages and the codes used for transmitting them.

THE DAILY WEATHER REPORT OF 1921-1922: FORMS OF MESSAGES AND CODES FOR TRANSMISSION

FIRST of all it is obvious that many new elements have to be coded and the symbolism becomes highly complicated; we therefore begin with a list of the algebraical symbols now in use.

THE SYMBOLS USED IN THE MESSAGES, ARRANGED IN ALPHABETICAL ORDER.

A = form of predominating cloud lowest in the scale of cloud forms.

a = form of predominating cloud highest in the scale of cloud forms when more than one type of cloud exists.

BBB = barometer in millibars and tenths (initial 9 or 10 omitted) or in millimetres and tenths (initial 7 omitted).

BB = barometer in whole millibars or whole millimetres (initial 9, 10 or 7 omitted).

For upper air reports of pressure, temperature and humidity, BB is in whole millibars with the hundreds figure omitted, whether this is 9, 8, 7, 6 or 5.

$B_1B_1B_1$ = barometric pressure in whole millibars in the upper air at the level of an inversion.

b = amount of barometric tendency in the three hours preceding the time of observation, expressed in half-millibars or half-millimetres.

C = form of predominating cloud according to the scale of cloud forms when only one form is reported, as from ships at sea.

C_1 = form of cloud observed by nephoscope for special cloud reports.

c = characteristic of barometric tendency during the period of three hours preceding the time of observation.

DD = direction of the wind near the ground on the scale (01—32).

dd = direction of the wind in the upper air on the scale (01—36).

d = direction from which the swell comes on scale (0—8).

d_s = direction of movement of ship on scale (0—8).

F = force of the wind on the Beaufort scale.

Forces above 9 reported as 9 in telegrams with the actual force in a word at the end, *e.g.*, force 10 is reported at the end as "storm ten," force 11 as "storm eleven." Ships at sea, however, report "gale ten," "storm eleven," "hurricane twelve."

GG = Greenwich time of observation (01 = 1 a.m., 12 = noon G.M.T., 24 = midnight G.M.T.).

H = relative humidity of the air.

h = height of base of lowest cloud present.

H_1 = heights at which upper air-temperature and humidity are reported.

h_1 = height at which upper wind is reported.

K = the characteristic of the swell in the open sea.

K′ = amount and characteristic of barometric tendency expressed by a single figure.

L = amount of sky (scale 0—10) covered by cloud of form "A" and of all forms of the same layer as "A" if "a" refers to a different layer.

LLL = latitude in degrees and tenths, the tenths being obtained by dividing the number of minutes by six and neglecting the remainder.
lll = longitude in degrees and tenths, as for latitude.
MM = the maximum temperature in the interval of eleven hours ending at 18 h G.M.T. (or at one of the hours 01 h, 07 h, 13 h, 18 h, G.M.T., following not less than four hours after noon, local time).
mm = the minimum temperature in the interval of thirteen hours ending at 7 h G.M.T. (or at the hour thirteen hours after the time of reporting the maximum temperature).
N = total amount of sky covered with cloud.
P = day of the week.
Q = quarter of the globe in which a ship is situated.
RR = rainfall in whole millimetres.
r = time of commencement of rainfall (precipitation).
S = the state of the sea and swell.
TTT = temperature of the air in degrees and tenths, Fahrenheit or Centigrade.
TT = temperature of the air in whole degrees Fahrenheit or Centigrade.
ttt = temperature of the sea (surface-water) in degrees and tenths.
tt = temperature of the sea (surface-water) in whole degrees.
t_1t_1 = increase of temperature at an inversion: in degrees.
V = visibility or distance at which objects can be seen in daylight (or at which lights can be seen at night).
v = visibility at sea from ships at sea.
V_s at coast stations only = visibility towards the sea.
VV = the relative speed of clouds as determined by the nephoscope and such that if "h" is the height of the cloud in metres, then the actual speed "vv" in kilometres per hour is obtained from the equation

$$vv = \frac{h}{1000} \times VV$$

vv = speed of the wind in the upper air in kilometres per hour.
W = the weather in the interval since the preceding time of report: this interval is five, six or seven hours for stations reporting four times daily.
ww = the actual weather at the time of observation, with which is combined, whenever possible, the general character of the weather.
x_1, x_2, etc. = check figures obtained by adding the first four figures of the group, and taking the units figure of the sum so obtained.
y_1, y_2, y_3, y_4 = check figures obtained by adding together the first, second, third or fourth figure of each of the preceding groups and taking the units figure of the sum.
z = key figure obtained by adding together all the x's or all the y's and taking the units figure of the sum.

Having thus enumerated the various items of information of which the messages may be made up, we may proceed to consider the forms in which the items are arranged.

The form of message agreed upon by the International Commission for Weather Telegraphy in 1920, and, with minor alterations, adopted

by the International Meteorological Committee in September, 1921, is set out thus :—

Reports from Land Stations.

In place of the four groups for a morning report preceded by two for the previous evening the basic form of message at any one of the term hours expressed in symbols is now :

BBBDD FwwTT cbWVH ALaNh

To these four an additional group is added twice daily as follows :—

For inland stations :

RRmmr for reports at 0700 G.M.T.
RRMMr for reports at 1800 G.M.T.

For coast stations :

RRSVsr for reports at 0700 and 1800 G.M.T.

Further, from certain selected stations, groups reporting the direction of motion and relative speed of the clouds are added in the symbolic form C_1ddVV.

The symbolic form of the reports of upper wind is h_1ddvv, and for upper air-temperature and humidity BBTTH.

Inversions of the lapse-rate [1] of temperature are reported at the end of the message by the addition of the groups 00000 $B_1B_1B_1t_1t_1$ where $B_1B_1B_1$ is the pressure in millibars at the level of the inversion and t_1t_1 is the increase of temperature at the inversion in degrees.

Reports by Radio-telegraphy from Ships at Sea.

As recommended by the Commission for Maritime Meteorology in September, 1921, it was agreed that the ordinary message from a ship should consist of two parts : the first a universal part which would be common to all services, and the second a national part arranged by the various countries to meet their special needs.

For the present we are concerned only with the universal part of the message for which there are two alternative forms according as it may be decided to include additional figures to be used for checking the accuracy of the transmission or to dispense with them. Check-figures (indicated in what follows by x, y, z) are figures derived from numerical operations on the original code-figures of the observers' message, by which a clue is given to the detection and correction of errors.

The basic form of the message expressed in symbols is :

PQLLL. lllGG BBDDF wwVKd (without check-figures).
$QLLLx_1$ $Plllx_2$ $BBDDx_3$ $FVKdx_4$ $wwGGx_5$ $y_1y_2y_3y_4z$
(with check-figures x, y, z).

Thus the check requires two groups to be added to the message. In the message where the check-figures x, y, z are used, five check-figures (x) in five groups and one group solely of check-figures

[1] Lapse-rate of temperature means the rate of fall of temperature with height as determined by observations of temperature in the upper air. An inversion of the lapse-rate means a change from the ordinary condition of fall of temperature with height to uniformity or rise with height.

($y_1y_2y_3y_1z$) provide a check on twenty observation-figures in five groups. In each of these five groups x_1 is the digit of units' place in the sum of the other figures in the group. The y's are the digits of the units' place in the sums of the columns of the five observation-groups written one under the other, and z is the digit in the units' place of the sum of the y's.

Other groups may be added as follows :—

For a message in millimetre-Centigrade units	CNTTT Wrttt
For a message in millibar-Fahrenheit units	CNTTd$_3$ WrttK

Besides the messages from land stations and ships there are also special reports for aviation intended to give information to pilots on established air-routes. These, however, are not published in the Daily Weather Report and do not therefore come within our present purpose.

Codes for Reports.

For these messages a large number of agreed codes are required ; they are as follows :—

1. Code for Barometer: Surface Observation. BBB.

The reading of the barometer corrected for index error, temperature, and gravity, and reduced to sea-level, in millibars and tenths (initial 9 or 10 omitted) or millimetres and tenths (initial 7 omitted).

2. Code for Amount of Barometric Tendency. b.

Taken from the barograph (half millibars) per three hours, if less than 10 the figure itself is reported whether the tendency be up or down.

If the figure taken from the barograph be one of the numbers 10, 11 . . . 19, the second cypher is reported and the wind-direction modified by adding 33.

If the figure taken from the barograph be one of the numbers 20, 21 . . . 29, the second cypher is reported and the wind-direction modified by adding 67.

If the figure taken from the barograph is greater than 29, report the figure 9 and add 67 to the wind-direction number, *i.e.*, numbers greater than 29 are reported as 29.

3. Code for Characteristic of Barometric Tendency. c.

0	Steady or rising . . .	The barometer is now higher than, or the same as, three hours ago.
1	Rising, then steady . . .	
2	Rising, then falling . . .	
3	Falling or steady, then rising .	
4	Unsteady but rising . . .	
5	Falling	The barometer is now lower than three hours ago.
6	Falling, then steady . . .	
7	Falling, then rising . . .	
8	Steady or rising, then falling .	
9	Unsteady but falling . . .	

4. CODE FOR BAROMETRIC CHANGE WHEN ONLY ONE FIGURE IS USED FOR AMOUNT AND CHARACTERISTIC. K′.

		Change in last three hours in half millibars.
0	Barometer steady	0 or 1
1	„ rising slowly . .	2 or 3
2	„ rising	4 to 7
3	„ rising quickly .	8 to 12
4	„ rising very rapidly	More than 12
5	„ falling slowly . .	2 or 3
6	„ falling	4 to 7
7	„ falling quickly .	8 to 12
8	„ falling very rapidly.	More than 12

5. CODE FOR WIND-DIRECTION. DD.

The code set out on p. 13 is used if the barometric tendency is 9 or less, but if the amount of the barometric tendency is greater than 9 and less than 20, 33 is added to the number used for reporting wind-direction, and if the amount is 20 or more, the number 67 is added to the number hitherto used for reporting wind-direction.

6. CODE FOR WIND-FORCE. F.

The Beaufort scale (p. 20). The words "storm 10," "storm 11," "storm 12" are added when the force is greater than 9.

7. CODE FOR PRESENT WEATHER. WW.

From the table below the first phrase which describes the present weather conditions is to be selected by the observer.

		Code No.
Thunderstorm or *Line Squall.*	Line squall, with hail	99
	„ without hail	98
	Heavy thunderstorm with hail (with gale) . .	97
	„ „ without hail (with gale) . .	96
	„ „ with hail (without gale) . .	95
	„ „ without hail (without gale) .	94
	Moderate thunderstorm with hail	93
	„ „ without hail	92
	Slight thunderstorm with hail	91
	„ „ without hail.	90
Hail or *Rain and Hail.*	Heavy continuous	89
	„ occasional	88
	„ but decreasing	87
	Moderate but increasing	86
	„ continuous	85
	„ occasional	84
	„ but decreasing	83
	Slight but increasing	82
	„ continuous	81
	„ occasional . . .	80

		Code No
Sleet or *Rain and Snow*	Heavy continuous	79
	„ occasional	78
	„ but decreasing	77
	Moderate but increasing	76
	„ continuous	75
	„ occasional	74
	„ but decreasing	73
	Slight but increasing	72
	„ continuous	71
	„ occasional	70
Snow or *Snow and Hail.*	Heavy continuous	69
	„ occasional	68
	„ but decreasing	67
	Moderate but increasing	66
	„ continuous	65
	„ occasional	64
	„ but decreasing	63
	Slight but increasing	62
	„ continuous	61
	„ occasional	60
Rain.	Heavy continuous	59
	„ occasional	58
	„ but decreasing	57
	Moderate but increasing	56
	„ continuous	55
	„ occasional	54
	„ but decreasing	53
	Slight but increasing	52
	„ continuous	51
	„ occasional	50
Drizzle.	Thick continuous	49
	„ occasional	48
	„ but decreasing	47
	Moderate but increasing	46
	„ continuous	45
	„ occasional	44
	„ but decreasing	43
	Slight but increasing	42
	„ continuous	41
	„ occasional	40
Passing Showers.	Heavy, with snow	39
	„ sleet	38
	„ hail, or rain and hail	37
	„ rain, becoming worse	36
	„ rain	35
	„ rain, becoming better	34
	Slight, with snow	33
	„ sleet	32
	„ hail, or rain and hail	31
	„ rain	30

			Code No.
Fog or *Mist.*	For some time becoming thicker	and apparently overcast	29
		but clear in zenith	28
	For some time without change	and apparently overcast	27
		but clear in zenith	26
	For some time becoming thinner.	and apparently overcast	25
		but clear in zenith	24
	Intermittent	and apparently overcast	23
		but clear in zenith	22
	Just begun	and apparently overcast	21
		but clear in zenith	20
Cloudy or *Overcast* (Cloud 6–10)	After thunderstorm		19
	With or after thunder and lightning in neighbourhood		18
	After snow, sleet, or hail		17
	After rain or drizzle		16
	After fog or mist (or dust storm)		15
	With solar or lunar halo		14
	Precipitation within sight		13
	Cloud increasing		12
	No apparent change		11
	Cloud decreasing		10
Fine or *Fair* (Cloud 0–5)	After thunderstorm		09
	With or after thunder and lightning in neighbourhood		08
	After snow, sleet, or hail		07
	After rain or drizzle		06
	After fog or mist (or dust storm)		05
	With solar or lunar halo		04
	Precipitation within sight		03
	Cloud increasing		02
	No apparent change		01
	Cloud decreasing		00

In order to connect this code with the weather as shown by the Beaufort letters, the present weather code may be abbreviated into the following table :—

PRESENT WEATHER CODE, SYMBOLIC VERSION.

	0	1	2	3	4	5	6	7	8	9
0	bc —	bc	bc +	bcjp	bc⊕	bc/f	bc/r	bc/s(h)	bctl	bc/tlr
1	co —	co	co +	cojp	co⊕	co/f	co/r	co/s(h)	cotl	co tlr
2	fb	fo	ifb	ifo	fb —	fo —	ifb	ifo	fb +	fo +
3	pr$_0$	ph$_0$	prs$_0$	ps$_0$	PR—	PR	PR +	PH	PRS	PS
4	d$_0$	d$_0$d$_0$	d$_0$ +	d —	d	dd	d +	D —	D	DD
5	r$_0$	r$_0$r$_0$	r$_0$ +	r —	r	rr	r +	R —	R	RR
6	s$_0$	s$_0$s$_0$	s$_0$ +	s —	s	ss	s +	S —	S	SS
7	rs$_0$	rs$_0$rs$_0$	rs +	rs —	rs	rsrs	rs +	RS —	RS	RSRS
8	h$_0$(r$_0$)	rh$_0$rh$_0$	h$_0$(r$_0$) +	h(r) —	h(r)	rhrh	h(r) +	H(R) —	H(R)	RHRH
9	tlr$_0$	tlrh$_0$	tlr	tlrh	TLR	TLRH	TLR	TLRH	KQ	KQH

A solidus (/) such as occurs in the combination "bc/r" separates weather at the time of observation from the preceding weather, bc/r thus indicating "fine or fair after rain or drizzle." Continuity is indicated by repetition and intensity by capitals, a suffix 0 meaning "slight." Thus rr means continuous rain, R heavy rain and r$_0$ light rain ; + means increasing, and — diminishing, in intensity or amount. Thus s + means snow becoming heavier.

Individually the letters have the following meanings :—

b = fine.
bc = fair.
c = cloudy.
d = drizzle.
f = fog.
h = hail.
i = intermittent (occasional).
j = adjacent (*i.e.*, in vicinity of station).

KQ = line squall.
l = lightning.
o = overcast.
p = passing showers.
r = rain.
s = snow.
t = thunder.
tlr = thunderstorm.

⊕ = halo.
= gale.

The following additional letters are in use :—

e = wet air without rain falling.
g = gloomy.
m = mist.
q = squally.
u = ugly, threatening
v = extreme visibility.
w = dew.
x = hoar frost.
y = dry air (humidity below 60 per cent.).
z = haze.

8. Code for Past Weather. W.

Without precipitation . .	0	Fair or fine (b or bc).
	1	Cloudy.
	2	Overcast continuously.
	3	Fog or mist.
	4	Thick fog.
Precipitation . . .	5	Passing showers.
	6	Rain or drizzle.
	7	Snow or sleet.
	8	Hail or rain and hail.
	9	Thunderstorm.

In using this code the number should be taken which describes the most important feature of the past weather not already reported by the two figures for "present weather" and "general character." This is usually the largest number of the scale appropriate to the occasion.

9. Code for Relative Humidity. H.

Code Figure.	Relative Humidity.	Code Figure.	Relative Humidity.
0 . .	95—100 per cent.	5 . .	50—59 per cent.
9 . .	90—94 ,,	4 . .	40—49 ,,
8 . .	80—89 ,,	3 . .	30—39 ,,
7 . .	70—79 ,,	2 . .	20—29 ,,
6 . .	60—69 ,,	1 . .	10—19 ,,

10. Code for Visibility for Ships at Sea. v.

The code for visibility on land is given by the numbers 0–9 of the scale of visibility on p. 25. The horizontal visibility for ships at sea is given by the figures 0—9 of the following scale :—

Code Number.			
0 = Dense fog . .	objects not visible at	50	yards.
1 = Thick fog . .	,, ,,	1	cable.
2 = Fog . . .	,, ,,	2	cables.
3 = Moderate fog .	,, ,,	½	mile (nautical).
4 = Thin fog or mist .	,, ,,	1	,, ,,
5 = Visibility poor .	,, ,,	2	miles ,,
6 = Visibility moderate	,, ,,	5	,, ,,
7 = Visibility good .	,, ,,	10	,, ,,
8 = Visibility very good	,, ,,	30	,, ,,
9 = Visibility exceptional.	objects visible more than	30	,, ,,

11. Code for Form of Cloud. A, a, C, or C_1.

Code Number.	Form of Cloud.	Code Number.	Form of Cloud.
1	Ci.	6	St.Cu.
2	Ci.St.	7	Nb.
3	Ci.Cu.	8	Cu. or Fr.Cu.
4	A.Cu.	9	Cu.Nb.
5	A.St.	0	St. or Fr.St.

12. Code for Height of Base of Lowest Cloud. h.

Code Number.	Height of Base of Cloud (metres).	Height of Base of Cloud (feet).
0	0— 50	0— 150
1	50— 100	150— 300
2	100— 200	300— 600
3	200— 300	600—1,000
4	300— 600	1,000—2,000
5	600—1,000	2,000—3,000
6	1,000—1,500	3,000—5,000
7	1,500—2,000	5,000—6,500
8	2,000—2,500	6,500—8,000
9	No low cloud.	No low cloud.

13. Code for Amount of Rainfall. RR.

For amounts of 0·7 millimetre or more report the amount to the nearest whole millimetre, *e.g.*, 17·2 reported as 17.

For amounts 0·1 to 0·6 use the following code :—

91	0·1	97.	Some rain, but not measurable.
92	0·2		
93	0·3	98.	More than 90 millimetres.
94	0·4		
95	0·5	99.	Measurement impossible or unreliable.
96	0·6		

14. Code for Time of Commencement of Rainfall (or other precipitation). r.

Code Number.				
0	No rain.			
1	Rain began	0— 1 hour before time of observation.		
2	„	1— 2 hours	„	„
3	„	2— 3 „	„	„
4	„	3— 4 „	„	„
5	„	4— 5 „	„	„
6	„	5— 6 „	„	„
7	„	6— 8 „	„	„
8	„	8—10 „	„	„
9	„	above 10 „	„	„
–	No observation.			

15. Code for Characteristic of Predominating Swell.

For Coast Stations (see p. 24).

For the Open Sea. K.

Code Number.			
0	Sea smooth to moderate	and	No, or slight, swell.
1			Moderate swell.
2			Heavy swell.
3			Long low swell.
4			Confused swell.
5	Sea rough	and	No, or slight, swell.
6			Moderate swell.
7			Heavy swell.
8			Long low swell.
9			Confused swell.

16. Code for Direction of Predominating Swell. d.

Code Number.	Direction	Code Number.	Direction.
0	No swell.	5	S.W.
1	N.E.	6	W.
2	E.	7	N.W.
3	S.E.	8	N.
4	S.		

17. Code for Quarter of the Globe and Indication of the Unit of Pressure Employed. Q.

		Code Number.	
Latitude.	Longitude.	For millibars.	For millimetres.
N.	W.	1	5
N.	E.	2	6
S.	W.	3	7
S.	E.	4	8

We have still to provide for certain abbreviated reports from Continental stations which are in the form :—

BBDDF w_1TTK′R for observations at 0700 G.M.T.
and BBDDF w_1TTK′W for observations at other hours.

This requires a new code for reporting rainfall in the preceding twenty-four hours, R, by one figure and an explanation of w_1 which is intended to represent present weather. The list of one hundred events which are numbered in Code 7 is reduced to one of ten events by using the first figure only of the former.

CODE FOR RAINFALL IN THE PRECEDING TWENTY-FOUR HOURS:—

Code Figure.		Code Figure.	
0 . .	No rain.	5 . .	10 to 15 mm.
1 . .	Trace, or 0·1 mm.	6 . .	15 to 20 „
2 . .	0·2 to 2 mm.	7 . .	20 to 30 „
3 . .	2 to 5 mm.	8 . .	30 to 50 „
4 . .	5 to 10 „	9 . .	Above 50 „

We are afraid that the reader will feel embarrassed by the richness of the information which is poured into the columns of the Daily Weather Report in contrast with the meagre representation contained in pp. 11 to 16. The situation which confronts us is that of a computer who is faced with the solution of a number of simultaneous equations. The calculation is quite an exhilarating exercise when the number of variables is two; it becomes rather tedious when a third variable joins with its equation; when there are ten any ordinary computer recoils from the task, and when there are twenty he seeks some other occupation.

As a step in the development of the science of forecasting the multiplication of data marks a fresh start; the tendency between 1860 and 1920 was rather to reduce them. When the drawing of weather maps began the full set of observations was telegraphed and the first conspicuous achievement of synoptic meteorology was to recognise the dominance of pressure and wind. The importance of the other elements receded. The temperature of the wet bulb, religiously recorded, came to be entirely disregarded, and even the temperature of the dry bulb was of so little account that when we came to arrange for messages from Atlantic liners it was very difficult to make out a case for including temperature or weather in the message. The position of the point in the barometric situation was of more importance than the local experience of the moment.

Now circumstances require great wealth of information, seven or eight thousand facts about the weather of a single day.

It is to be hoped that the study of the multitude of facts will bring us some new generalisation which will economise thinking in the same way that the drawing of isobars did from 1860 onward. Until the material placed at our disposal is peptonised in some such way there is some danger of its causing indigestion.

While this work has been passing through the Press further changes have taken place in the Daily Weather Report. Solar radiation has been omitted. Radio disturbances have appeared, and a code for the condition of the ground.

CHAPTER II

CLOUDS

THE INTERNATIONAL CLASSIFICATION

The introduction of the forms of the various clouds into the daily reports of the Weather-Services brings the nomenclature and practice of identification of cloud-forms within the inner region of the science and art of forecasting. It is a subject which I approach with some diffidence because the accumulated experience of the last fifty years leads me to feel that the first stage in the classification of clouds has been passed and the new one which should succeed it has hardly arrived.

The difference in the forms of clouds is one of the most striking of natural phenomena, and it is curious that no systematic nomenclature was adopted until Luke Howard, a London chemist and devoted meteorologist, laid down the lines of classification in an "Essay on the Modifications of Clouds," published in 1803. During the nineteenth century a good deal of attention was paid to the subject by the Hon. R. Abercromby, Rev. Clement Ley, MM. A. Riggenbach, H. H. Hildebrandsson, L. Teisserenc de Bort, L. Rotch, H. Mohn, and others.

The Hon. R. Abercromby called attention to the remarkable fact that the various types of cloud were common to the whole earth, and in course of time an International Cloud Atlas was prepared with remarkably good illustrations in chromolithograph produced in Zürich. It soon went out of print and a new edition was prepared in 1910, which was again rapidly disposed of and is now unobtainable. It is upon the definitions of that atlas that, for the most part, meteorologists rely. But other cloud-atlases or collections of cloud-photographs have been produced with much more elaboration of nomenclature by J. Vincent (Brussels, 1909), and A. W. Clayden (London, 1905).

The classification of Vincent has been followed in cloud-atlases by Loisel (Paris, 1911), and Taffara (Rome, 1917), while the international classification has been adhered to by the United States Weather Bureau (Washington), by the Meteorological Office (London), and by G. A. Clarke (London, 1920).

The line of comment which the international classification seems to call for is that the subject really resolves itself into three parts: first, the identification and nomenclature of the forms of individual clouds, and second, the grouping of individual clouds first into lines, secondly into layers of detached cloud, thirdly into corrugated layers, and finally into continuous layers of cloud where visible structure is lost. The third part is suggested by the modifications which the various individual clouds or groups take on at different heights.

In the international classification individual clouds and groups of clouds, linear, tesselated, and continuous, seem to be similarly regarded. And there is one other point to notice. Although the ancients had no names for what we recognise as separate forms of clouds, they did have two names, *nubes* and *nebula*; there is an essential difference between their meanings of which the international classification takes no advantage. The name *nebula* does, indeed, appear in *cirro-nebula*, the milkiness of the upper sky which causes halos. But the same kind of milkiness often appears lower down and at the surface itself what we instinctively call mist is *nebula*, not *nubes*. It pervades large regions with no recognisable boundaries, and we might do well to rescue the term for more general use.

The definitions of cloud-forms on the international classification with the addition of *Alto-Cumulus-Castellatus* and of certain clouds with smooth outlines which are characterised as *lenticular* because some of the most conspicuous are lens-shaped, are set out in a book of " Cloud Forms " published by the Meteorological Office. We shall quote twelve definitions from that work. We have added another definition, No. 13, *Pallio-Nimbus* from M. Vincent's classification. For *Fog*, the fourteenth type, we have made a definition of our own.

1. [1]CIRRUS (CI.).—*Detached clouds of delicate appearance, fibrous (thread-like) structure and feather-like form, generally white in colour.* Cirrus clouds take the most varied shapes, such as isolated tufts of hair, *i.e.*, thin filaments on a blue sky, branched filaments in feathery form, straight or curved filaments ending in tufts (called CIRRUS UNCINUS), and others. Occasionally cirrus clouds are arranged in bands, which traverse part of the sky as arcs of great circles, and as an effect of perspective appear to converge at a point on the horizon, and at the opposite point also if they are sufficiently extended. Cirro-stratus and cirro-cumulus also are sometimes similarly arranged in long bands.

2. CUMULUS (CU.) (Woolpack or Cauliflower Cloud).—*Thick cloud of which the upper surface is dome-shaped and exhibits protuberances while the base is generally horizontal.* These clouds appear to be formed by ascensional movement of air in the day-time which is almost always observable. When the cloud and the sun are on opposite sides of the observer, the surfaces facing the observer are more brilliant than the margins of the protuberances. When, on the contrary, it is on the same side of the observer as the sun, it appears dark with bright edges. When the light falls sideways, as is usually the case, cumulus clouds show deep shadows.

True cumulus has well-defined upper and lower margins ; but one may sometimes see ragged clouds—like cumulus torn by strong wind—of which the detached portions are continually changing ; to this form of cloud the name FRACTO-CUMULUS may be given.

3. ALTO-CUMULUS-CASTELLATUS.—"*Little miniature cumulus rising in many heads from a more or less compact layer of alto-cumulus.*" "Not a very common cloud in these latitudes but sometimes seen in summer, and when coming from a westerly or south-westerly point almost always a sign of the approach of shallow depressions which bring thunderstorms."[2]

[1] It may be noted that the outline of the sun is visible, and his rays cast a shadow in spite of the presence of clouds of this type, unless the clouds and the sun are both low down on the horizon.

[2] Captain C. J. P. Cave, R.E. "The Forms of Clouds," "Q. J. Roy. Met. Soc.," Vol. XLIII., p. 68. 1917.

4. Cumulo-Nimbus (Cu.-Nb.), the Thunder Cloud; Shower Cloud.—*Great masses of cloud rising in the form of mountains or towers or anvils, generally having a veil or screen of fibrous texture (false cirrus) at the top and at its base a cloud-mass similar to nimbus.* From the base local showers of rain or of snow, occasionally of hail or of soft hail, usually fall. Sometimes the upper margins have the compact shape of cumulus or form massive heaps round which floats delicate false cirrus. At other times the margins themselves are fringed with filaments similar to cirrus-clouds. This last form is particularly common with spring showers. The front of a thunderstorm of wide extent is frequently in the form of a large low arch above a region of uniformly lighter sky.

5. Stratus (St.).—*A uniform layer of cloud, like fog not lying on the ground.* The cloud-layer of stratus is always very low. If it is divided into ragged masses in a wind or by mountain tops, it may be called Fracto-Stratus. The complete absence of detail of structure differentiates stratus from other aggregated forms of cloud.

6. [1] Cirro-Stratus (Ci.-St.).—*A thin sheet of whitish-cloud; sometimes covering the sky completely and merely giving it a milky appearance; it is then called* Cirro-Nebula *or cirrus haze; at other times presenting a more or less distinctly fibrous structure like a tangled web.* This sheet often produces halos round the sun or moon.

7. [1] Cirro-Cumulus (Ci.-Cu.).—Mackerel Sky.—*Small rounded masses or white flakes without shadows, or showing very slight shadow; arranged in groups and often in lines.* French, *Moutons*; German, *Schäfchen-wolken*.

8. Alto-Stratus (A.-St.).—*A dense sheet of a grey or bluish colour, sometimes forming a compact mass of dull grey colour and fibrous structure.* At other times the sheet is thin like the denser forms of cirro-stratus, and through it the sun and the moon may be

[1] It may be noted that the outline of the sun is visible, and his rays cast a shadow in spite of the presence of clouds of these types, unless the clouds and the sun are both low down on the horizon.

seen dimly gleaming as through ground glass. This form exhibits all stages of transition between stratus and cirro-stratus, but according to the measurements its normal altitude is about one-half of that of cirro-stratus.

9. ALTO-CUMULUS (A.-CU.).—*Larger rounded masses, white or greyish, partially shaded, arranged in groups or lines, and often so crowded together in the middle region that the cloudlets join.* The separate masses are generally larger and more compact (resembling strato-cumulus) in the middle region of the group, but the denseness of the layer varies and sometimes is so attenuated that the individual masses assume the appearance of sheets or thin flakes of considerable extent with hardly any shading. At the margin of the group they form smaller cloudlets resembling those of cirro-cumulus. The cloudlets often group themselves in parallel lines, arranged in one or more directions.

10. STRATO-CUMULUS (ST.-CU.).—*Large lumpy masses or rolls of dull grey cloud, frequently covering the whole sky, especially in winter.* Generally strato-cumulus presents the appearance of a grey layer broken up into irregular masses and having on the margin smaller masses grouped in flocks like alto-cumulus. Sometimes this cloud-form has the characteristic appearance of great rolls of cloud arranged in parallel lines close together. (ROLL-CUMULUS in England, WULST-CUMULUS in Germany.) The rolls themselves are dense and dark, but in the intervening spaces the cloud is much lighter and blue sky may sometimes be seen through them. Strato-cumulus may be distinguished from nimbus by its lumpy or rolling appearance, and by the fact that it does not generally tend to bring rain.

11. LENTICULAR CLOUD BANKS.—*Banks of cloud of an almond or airship shape, with sharp general outlines, but showing, on close examination, fretted edges, formed of an ordered structure of cloudlets similar to alto-cumulus or cirro-cumulus which is also seen in the bank itself when the illumination is favourable.* Sometimes the body of the cloud bank is dense, and the almond shape is complete, fore and aft, but sometimes the bank thins away from the forward edge to clear sky within, so that the bank presents the appearance

of a horse-shoe seen in perspective from below at a great distance. The bank appears nearly or quite stationary, while the cloudlets move rapidly into it at one side and away from it at the other.

12. NIMBUS (NB.).—*A dense layer of dark, shapeless cloud with ragged edges from which steady rain or snow usually falls. If there are openings in the cloud an upper layer of cirro-stratus or alto-stratus may almost invariably be seen through them.* If a layer of nimbus separates in strong wind into ragged cloud, or if small detached clouds are seen drifting underneath a large nimbus (the "SCUD" of sailors), either may be specified as FRACTO-NIMBUS (Fr.-Nb.).

The following remarks are added in the international atlas as instructions to observers.

(*a*) In the daytime in summer all the lower clouds assume, as a rule, special forms more or less resembling cumulus. In such cases the observer may enter in his notes STRATUS- or NIMBUS-CUMULIFORMIS.

(*b*) Sometimes a cloud will show a mammillated surface and the appearance should be noted under the name MAMMATO-CUMULUS.

(*c*) The form taken by certain clouds particularly on days of sirocco, mistral, föhn, etc., which show an ovoid form with clean outlines and sometimes irisation, will be indicated by the name LENTICULAR, for example: CUMULUS-LENTICULARIS, STRATUS-LENTICULARIS (Cu.-lent., St.-lent.).

(*d*) Notice should always be taken when the clouds seem motionless or if they move with very great velocity.

13. PALLIO-NIMBUS.—*A pall of cloud covering the whole sky which may be described as of the same type as alto-stratus but from which rain falls.*

We add a new definition :—

14. FOG.—A cloud, devoid of structure, formed on land in the layers of air which, though nearly stationary, really move slowly over the ground. The same kind of surface cloud may be found at sea in nearly calm weather or with wind of nearly

any force. Viewed from a distance fog has a definite boundary, whereas some other forms of obscurity have not.

It may be well to group these cloud-forms into cloud-sheets and heap-clouds, as is done in the article on Clouds in the "Meteorological Glossary," because a cloud-sheet, whether continuous or broken up into detached clouds or cloudlets, is an expression of stratification in the atmosphere for which some general explanation must be sought in due course. Such an explanation will have to be applicable to the higher cloud-sheets as well as to the lower. All cloud-sheets seem to be related in some way to the turbulence of the atmosphere. The relationship is already clear in the case of fog which arises from the absorption, by the ground or sea-surface, of heat from the warmer air passing over it with eddy-motion, and the explanation has been extended to the formation of layers of strato-cumulus in air-currents of long "fetch" and to the initiation of the layers of detached cumulus-clouds of the trade-winds. There seems no reason for attributing the other cloud-layers to a different physical process so that we may look forward to some extension in future of the general theory of eddy-motion which will bring the rest of the cloud-sheets into line. On the other hand, cirrus, the threadlike streaks of cloud in a pale blue sky, and false cirrus, the tufts, with threadlike structure, that generally lie on thunder clouds, are forms of cloud which are distinctive whether they are gathered into sheets or appear as detached masses in the sky. We cannot, apparently, be certain whether the false cirrus (or the true cirrus, indeed) is always to be regarded as belonging to great heights; it is rather the index of a special form of structure. Mr. G. A. Clarke has often pointed out that the forms of cirrus are simulated by clouds with great variety of height and Captain C. K. M. Douglas judges them all to be composed of ice-crystals. The presumption is that the word "cirrus" defines a characteristic form of cloud consisting of ice-crystals arranged in lines, whatever the height may be.

And, again, the use of lenticular clouds to form a separate group of classes is worthy of careful consideration. It seems right to

regard them rather as the *loci* within the boundary of which cloudlets are formed and outside which they evaporate ; so that the smooth appearance resolves itself into a fretwork of cloudlets, forming in the wind as it passes through the cloud-region, and evaporating from it as it emerges. The process is necessarily dynamical and the peculiar dynamical conditions are apparently due to the configuration of the ground.

Our illustrations of clouds (Figs. 7 and 8) will therefore be arranged as follows :—

1. A group of eight **Cloud-Forms** (Fig. 7) two specimens of cirrus, one of false cirrus, one of cumulo-nimbus (the thunder-cloud), one of alto-cumulus-castellatus (the precursor of thunder-storms), one of detached cumulus (the post-meridian cloud of fine weather), one of detached stratus (the typical form of eddy-cloud due to the combination of thermal convection with eddy-motion) and finally fog (the typical form of cloud due to eddy-motion operating against thermal convection).

2. A group of five **Cloud-Sheets**. Two of extensive layers, namely, cirro-stratus, the sheet of ice crystals which gives rise to halos, alto-stratus in the next lower stage, mostly water-globules which may give coronas, or iridescence, but not halos. Three groups of cloudlets, namely, cirro-cumulus (the mackerel sky) alto-cumulus, with rather larger cloudlets large enough to show shadows, and strato-cumulus, its grosser counterpart of the lower layers.

3. A group of three types of **Lenticular Cloud** which are neither continuous sheets nor layers of detached cloudlets, but cloudlets which are passing through a cloud-mass and giving it a false appearance of smoothness and persistence. Two of them are lenticular clouds of the evening sky, and the third a cloud-form peculiar to the region of Mount Etna and called Contessa del Vento.

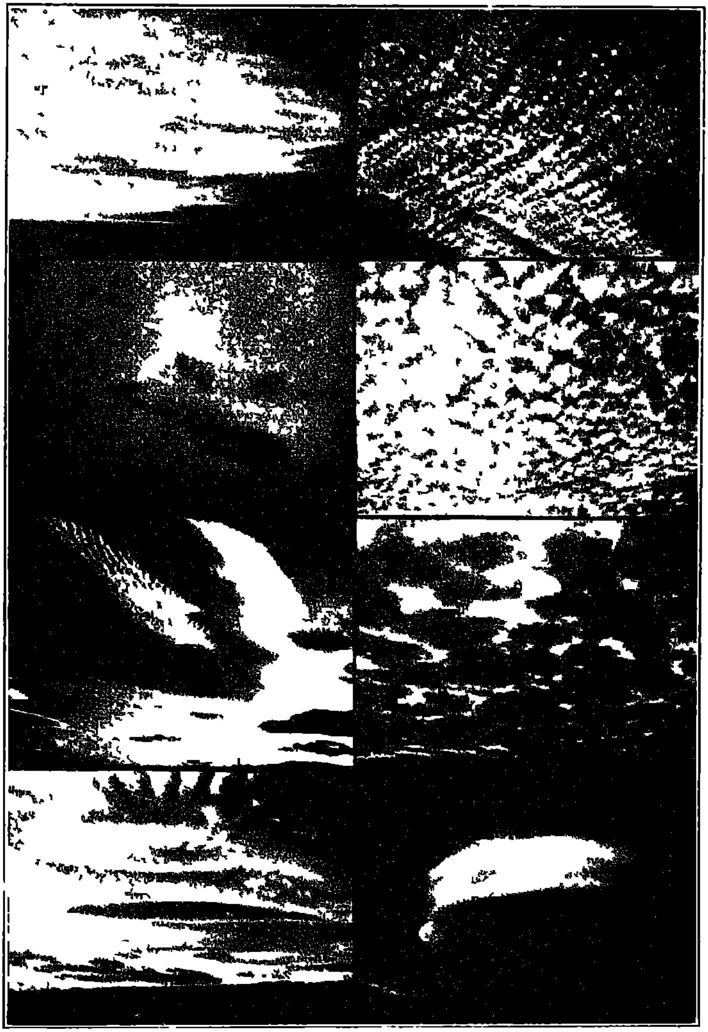
For other illustrations of cloud-forms the reader may be referred to the work on "Clouds" by G. A. Clarke. Constable & Co., Ltd., 1920.

FIG. 7.—CLOUD FORMS.

a. Cirrus (9,000 m.). G. A. Clarke.
d. Cumulo-nimbus, Ceylon (1,400 m to 8,000 m.). Evans
e Cumulus. Evening in the Indian Ocean (1,400 m. to 1,800 m.). Major W. J. S. Lockyer.
h. Fog on the ground. Capt C. J. P. Cave

b. Cirrus spiral (height unknown) G. A. Clarke.
c False cirrus (*cir.* 3,000 m). G A Clarke.
f Alto-cumulus-castellatus (3,000 m to 7,000 m.). G. A Clarke
g. Detached stratus (under 1,000 m) Capt. C. K. M Douglas.

FIG 8.—CLOUD SHEETS AND LENTICULAR CLOUDS.



a Cirro stratus (9,000 m.). G. A. Clarke.
b. Alto stratus (3,000 m. to 7,000 m.) G. A. Clarke
f Alto stratus lenticularis (perhaps 5,000 m.) G. A. Clarke.
g. Alto-cumulus-lenticularis (perhaps 5,000 m.) G. A. Clarke

c Cirro-cumulus (5,000 m. to 7,000 m.) G. A. Clarke
d Alto-cumulus (3,000 m. to 5,000 m.) G. A. Clarke.
e Strato cumulus (below 2,000 m.) G. A. Clarke
h Contessa del Vento (cumulus-lenticularis) L. Taffara

THE HEIGHT OF CLOUDS

Besides the specification of the type of cloud, reports are now required also of the direction in which the clouds are moving and of their speed. The direction of motion is obtained by the aid of a nephoscope which, with observers in this country, usually takes the form of Fineman's black-mirror nephoscope, a small portable instrument, or Besson's comb, a large contrivance in the shape of a huge comb at the top of a tall rod. It can be fixed out of doors. Details of the practical instructions for the use of these instruments are given in the "Observer's Handbook," M.O. 191.

The determination of the speed of motion is a more difficult matter. The angle through which a selected point of the cloud moves in a measured time with reference to a point on the ground immediately beneath it can be obtained satisfactorily from observations with the nephoscope, but that can only be transformed into actual velocity if the height of the cloud is known.

To get the height of the cloud which is the particular object of the observation, we could use an aviator's note if he would fly up to the cloud and read his height on reaching it, or the height can be calculated if the angular elevation of the cloud from two points is accurately observed. A simple form of this method, which is very effective at night time, is to set the beam of a searchlight vertical and read off the height of the patch of the cloud which is illuminated by the light by sighting on a graduated vertical rod, suitably placed at a known distance from the searchlight, and sighted by an observer's eye placed in a suitable fixed position. For the day-time two theodolites have to be used, or two mirrors arranged to view the same point of a cloud by two observers a considerable distance apart, who are in communication by telephone. Observations of a pilot balloon also give the height of any cloud into which the balloon actually plunges. But it requires expert judgment to distinguish between going into a cloud and getting behind a lower cloud which is nearer to the observer.

If none of these methods is available some information can be

gleaned from the type of cloud because measurements of the different types show notable differences of height. The heights of clouds in England are not apparently a favourite subject for English meteorologists and we have no official table of the heights of clouds. Mr. A. W. Clayden in his book on "Cloud Studies," gives the following :—

	Number of Observations.	Maximum Altitude.	Minimum Altitude.	Mean Altitude.
		m.	m.	m.
Cirrus . . .	58	27,413	4,114	10,230
Cirro-stratus . .	64	15,503	3,840	9,540
Cirro-cumulus . .	63	11,679	3,657	8,624
Alto-cumulus . .	83	9,390	1,828	5,348
Cumulus top . .	42	4,582	—	3,006
Cumulus base . .	48	1,959	584	1,290
Strato-cumulus .	27	6,926	823	2,248
Cumulo-nimbus top .	15	6,409	2,004	3,002
Cumulo-nimbus base	15	2,286	766	1,045

The mean values agree reasonably well with the heights given by Hildebrandsson as the result of the discussion of the observations of clouds in many countries by international co-operation in the year 1896—97.

It is said that when no observational method is available an experienced person can tell the height of lower clouds by inspection. It is a great gift : for those who do not possess it and have only a nephoscope the practice recommended by international agreement is to give the angular velocity of the cloud as the actual velocity on the supposition that the height is 1,000 metres. If h is the height in metres, V the actual velocity, and v the velocity of the imaginary cloud at 1,000 metres

$$V = v\,.\,h/1{,}000 \text{ or } v = 1{,}000\,.\,V/h.$$

It would be of great assistance in this part of the subject if it were possible to get a large plane mirror set at 45 degrees to the horizon with a sufficiently true surface to throw a second image of the zenith on the field of a camera obscura. The first image would be obtained from immediately above the lens of the camera obscura. If things could be so arranged, whenever clouds crossed

the zenith two images appear in the field, one following the other at a fixed distance according to the height of the cloud.

Things might possibly be arranged so that the images were separated by two centimetres when the cloud was at 1,000 metres and by two millimetres when the cloud was at 10,000 metres. If that were done an observer watching the field of the camera would be able to tell the direction of motion by the track of the clouds, the height of the cloud by the separation of the images, and by a little strain on the imagination the vertical velocity would be given by the change in the distance of the images. He could thus get a stereoscopic view of the sky and read off what is now difficult even to guess at.

The reader who wishes to follow up the meteorological inferences to be drawn from the study of clouds should consult the reports published in various countries of the observations made in the international cloud-year 1896–7. References are given in the summary of results which appears in Chapters IV. and VII. of the second volume of the remarkable work by Hildebrandsson and Teisserenc de Bort, "Les Bases de la Météorologie dynamique." Chapter IV. gives the bearing of observations of the direction of motion of clouds in all parts of the world upon the general circulation of the atmosphere, and Chapter VII. gives a summary of the results of observations of height and velocity of motion of clouds in Norway, Sweden, Russia, Germany, France, Canada, United States, India, and the Philippines. Great Britain took no part in that enterprise.

CHAPTER III

THE METHOD OF FORECASTING BY SYNOPTIC CHARTS
THE GENERAL METEOROLOGICAL RELATIONSHIPS IN THE REGION OF THE BRITISH ISLES

Before entering upon the special consideration of the details of conditions of our own area, meaning thereby that included within the limits of our daily charts, it will be desirable to glance for a moment at some of the meteorological features of its geographical position. For that purpose let me refer to two charts in the "Barometer Manual for the Use of Seamen." The one represents the average distribution of pressure and winds over the globe in the month of January (Fig. 9), and the other the corresponding information for July (Fig. 10). Another map of the normal distribution of pressure and prevailing winds for July which was prepared for a work on "The Air and its Ways" is given as Fig. 11. Its form is more convenient for the study of the regions near the pole than the charts on Mercator's projection which are more appropriate for the inter-tropical belt.

It is the distribution of land and sea and the contrast of the distribution of pressure in summer and winter to which I wish specially to call attention. As regards land and sea, it will be noticed that the area of our charts is the region of transition from the Atlantic Ocean to the Eurasian continent, the greatest continuous land-area of the globe. And as regards pressure, it must be noticed that over the Atlantic area, the transition from winter to summer shows very little change in the general distribution of pressure, chiefly a strengthening of the pressure in the permanently "high" regions of the 35th parallel, and at the same time a weakening of the slope to the trough of depression between Iceland and Greenland, whereas over the land areas, as the winter changes to summer, the great winter high-pressure area of central Asia is replaced by a region of marked low pressure.

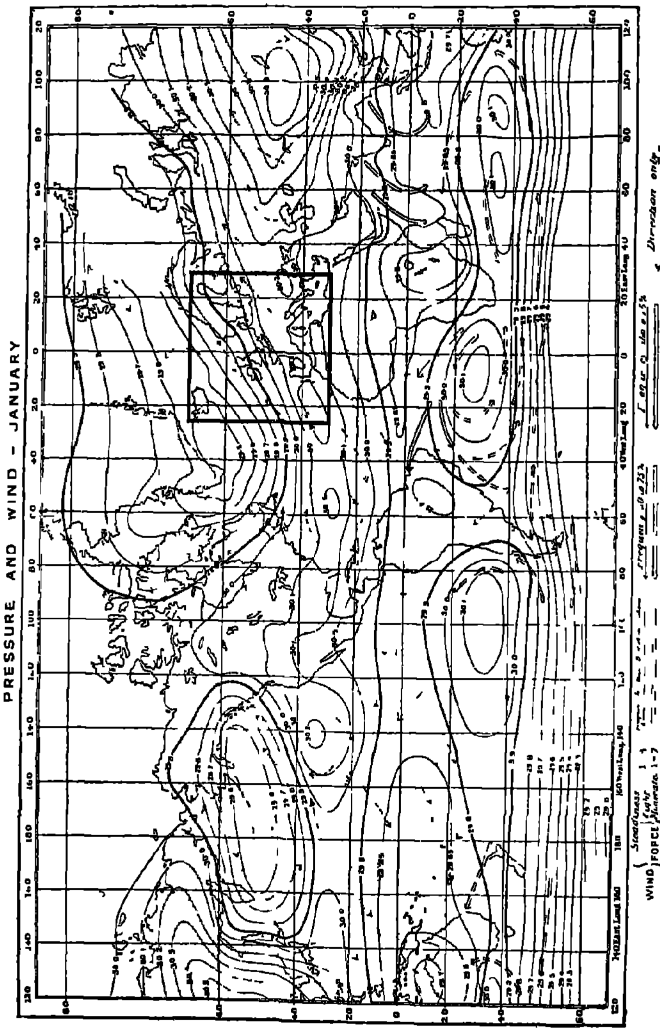


FIG. 9.—Normal Pressure and Winds over the Globe.

The limits of the area represented in the "Daily Weather Report of the Meteorological Office," 1910, are indicated approximately by a rectangular frame.

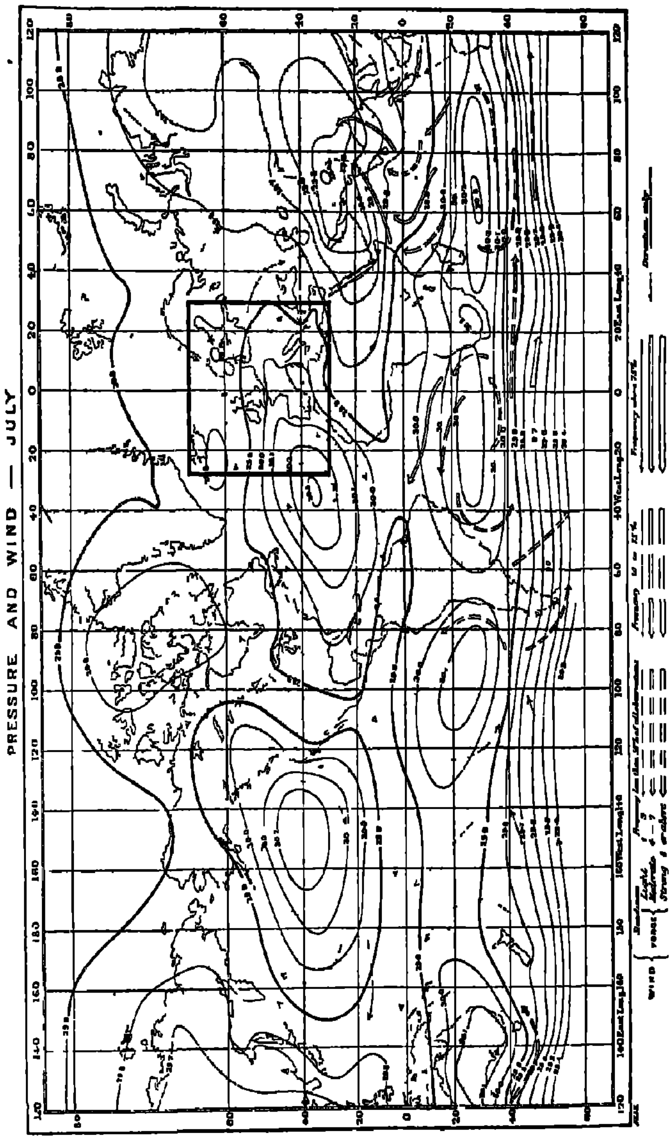


FIG. 10.—Normal Pressure and Winds over the Globe.
The limits of the area represented in the "Daily Weather Report of the Meteorological Office," 1910, are indicated approximately by a rectangular frame

Hence, while the whole general circulation of the atmosphere elsewhere is changed, the particular region of our islands shows merely an equalising of the pressure from south to north, and a

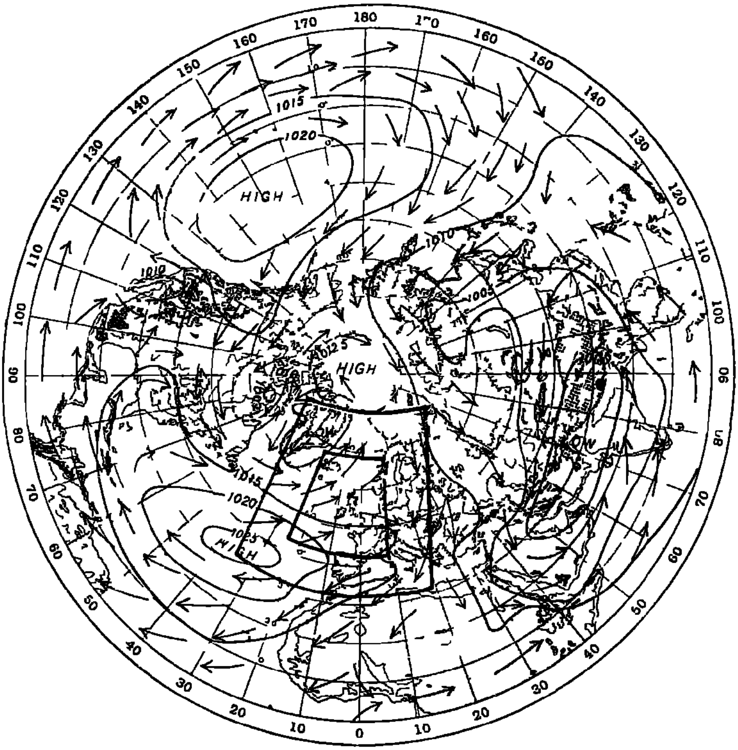


FIG 11.—Isobars and Winds corresponding therewith over the Northern Hemisphere in July. The limits of the area represented in the British and International Sections of the "Daily Weather Report of the Meteorological Office are indicated by the black frames. Pressures are given in millibars.

gradual decline of intensity of the conditions rather than a change of general type

In the winter a great high pressure area extends from Mexico across the Atlantic, southern Europe, and northern Africa to eastern Asia, and along the northern margin of this region a succession of low-pressure areas will be found with

interruptions due to variations of pressure, sometimes on the larger scale, sometimes on the smaller scale. The most important variations are the extensions southward or eastward of the high-pressure area which forms the variable northern or north-western boundary of the low-pressure region of the North Atlantic.

In the summer the high pressure area of the Atlantic just north of the tropic becomes more pronounced and more isolated, and the intensity of the low pressure region further north is very much reduced; there is a general tendency for low pressure to establish itself over the continental areas as the mean temperature of the day increases.

Hence the region with which we are concerned is particularly well situated for watching the changes in the general meteorology of the hemisphere. At times we seem to belong to an eastern extension of the permanent Atlantic high pressure, at other times we find ourselves on the western margin of the high pressure of the continental winter; at others, again, our conditions are dominated by an extension south-eastward of the high pressure usually associated with Greenland, and at others we share in the circulation which is determined by a high pressure area over Scandinavia. These varieties of condition are to some extent seasonal, but any variety may occur at any season of the year. And since the general march of events in weather is from west to east our region is peculiarly marked as an out-post for the great land areas which lie to the eastward. The British Isles—placed as they are on the extreme western margin of the high pressure area, which in the winter is characteristic of Europe and Asia—seem always to be on the brink of impending meteorological changes. And it is upon watching the gradual process of these changes that the method of modern forecasting depends.

Recently the region of observations has been extended towards the north-west in Iceland and still more recently to Spitsbergen (1913), and towards the south-west to include Gibraltar and the Portuguese Islands. While the text of this paragraph has been

under revision observations have been inaugurated at Jan Mayen, between Iceland and Spitsbergen, and at Bear Island, between North Cape and Spitsbergen. These observations we owe to the enterprise of the Norwegian Government. The advantages of the extensions will be apparent. To the encroachments and recessions of the polar high-pressures on the western side of our area the observations from Iceland and the other northern islands furnish our only clues. On the other hand the Azores and Madeira are generally on the northern and north-eastern margin of the permanent Atlantic anticyclone, and the observations from these regions indicate to us the changes that are in progress in that dominant element of the situation. In course of time it may be possible to find an answer to an inquiry which I think must be productive, and that is, how the north-east trade-wind is fed. That great permanent current may fairly be regarded, at least in part, as the drainage of surface air from the region between Africa and the Azores. The general circulation in July which is indicated in Fig. 11, throws some light on the matter. The supply is kept up, but not as a constant current from any particular part of temperate latitudes. The fluctuations of the stream must correspond with fluctuations of the weather within the region of our daily charts. Probably our own north-easterly winds form in their turn a part of the supply; our south-westerly winds certainly do not. When the completion of our maps gives us the opportunity of finding an answer to this question we may obtain some guiding principle that will throw light upon the complexity of the conditions of our region. In the meantime we use the charts for the continued application of the ordinary principles of forecasting which were developed in the period from 1851 to 1885.

RELATION TO THE UPPER AIR

The exploration of the upper air within the last twenty years which is referred to in Chapter XV., enables us now to supplement the representation of our position in relation to our environment by adding a diagram to show the results of measurements of temperature of the upper air over the globe. It is given in Fig. 12,

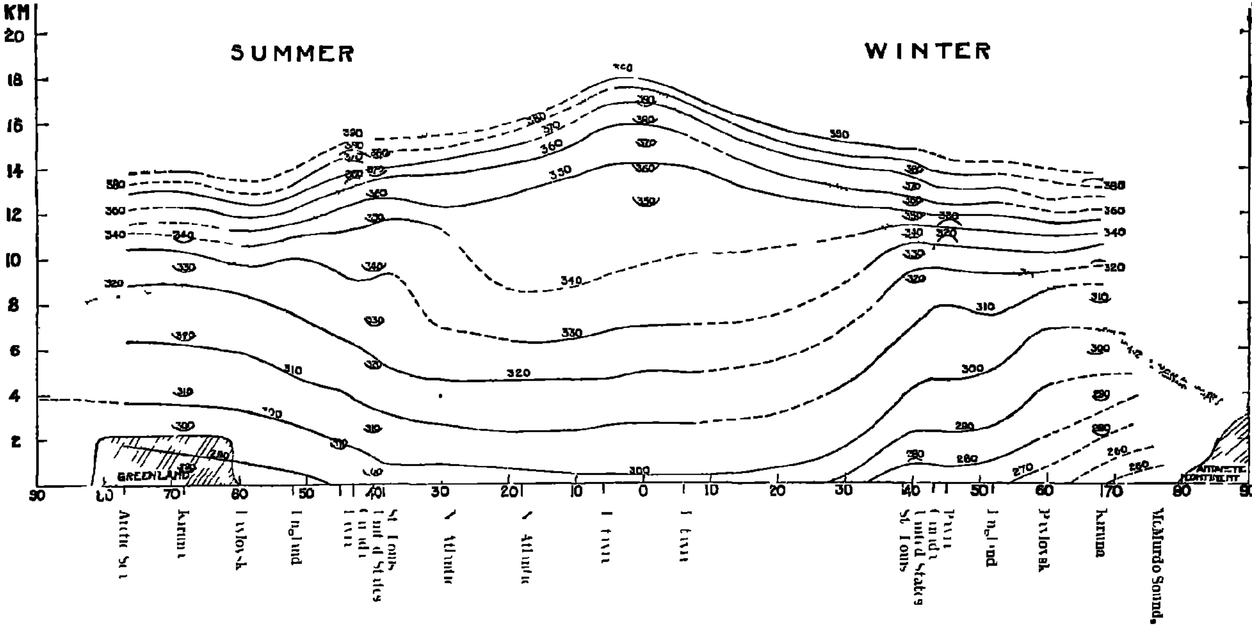


FIG. 12.—The Upper Air. Potential Temperature on the tercentesimal scale in a Section from Pole to Pole, using the winter observations of northern latitudes in default of observations at corresponding latitudes in the southern hemisphere. The shaded band is intended to indicate the probable position of the "tropopause" (see p. 409).

which shows the normal thermal condition of the atmosphere in a section from pole to pole extending from the surface up to 20 kilometres. For the purpose of this diagram the actual temperature is not used, but the "potential temperature" of the air at the various levels. By potential temperature of any specimen of air is meant the temperature which the air would indicate if its pressure were changed to a standard pressure under conditions which allowed of no escape of heat. Such conditions would be satisfied with sufficient accuracy if the air were forcibly brought down from its level to the surface. Hence the lines of the diagram show the temperature on the tercentesimal scale which would be indicated by the various samples of air if they were somehow brought down to the surface, without any provision for reducing the temperature which would naturally result from the compression.

The reason for representing temperature in this way is that there is a very prevalent idea of air coming down, in anticyclones or elsewhere, from the upper regions of the atmosphere to the surface.

The diagram shows what the temperature of the air would be when it arrived at the surface in the absence of any suitable processes for getting rid of the heat. The temperatures of the upper air viewed in this way are much too high for our experience; consequently we must find a way for the superfluous heat to escape before we can accept suggestions of rapidly descending air.

We cannot speak so easily of the relationships of ascending air because these are affected by the condensation of water and we should have to consider the thermodynamic properties of saturated air, whereas for descending air which is warmed by the increase of pressure the thermodynamic laws of dry air apply.

WEATHER FORECASTING

Forecasting by means of synoptic charts was begun in this country by Admiral FitzRoy in Parliament Street just over sixty years ago. He adopted that special application of the Anglo-Saxon word in order to avoid the connotations of the words prognostic and prophecy. He began his systematic study of

the subject with the preparation of maps to represent the conditions of the storm which wrecked the *Royal Charter* in 1859. In the method chosen for representing the distribution of the meteorological elements he followed Dove.

From that time onwards there was a gradual development of the method of using synoptic charts for anticipating the weather. By 1885 the method had practically taken the form in which it is employed in the present day. The rules that had become established were formulated at the request of the Meteorological Council, and published in that year in a small book by the Hon. Ralph Abercromby, an experienced sailor, a keen observer, and an acute meteorologist, whose early death was an irreparable loss to meteorological science.

The book to which I have referred was the latest official exposition of the principles of forecasting by means of weather charts, and I have therefore used it as the basis of the earlier chapters of this work which deal with the practice of forecasting. I shall endeavour later on to point out the advances that have been made in that department of our knowledge of the weather in the last thirty-five years. Throughout the book I have kept in mind the physical processes which, so far as we know, must be followed in the production of the various phenomena of weather. I have given a brief exposition of these processes in Chapter VIII., and in dealing with my subject I have endeavoured to bring the empirical laws of forecasting into relation with the physical processes.

The fundamental principle of the method is that weather travels, and that if we can find out what weather there is within range and in what direction it is travelling we can warn one part of our area of changes that have already shown signs of their appearance in some other part.

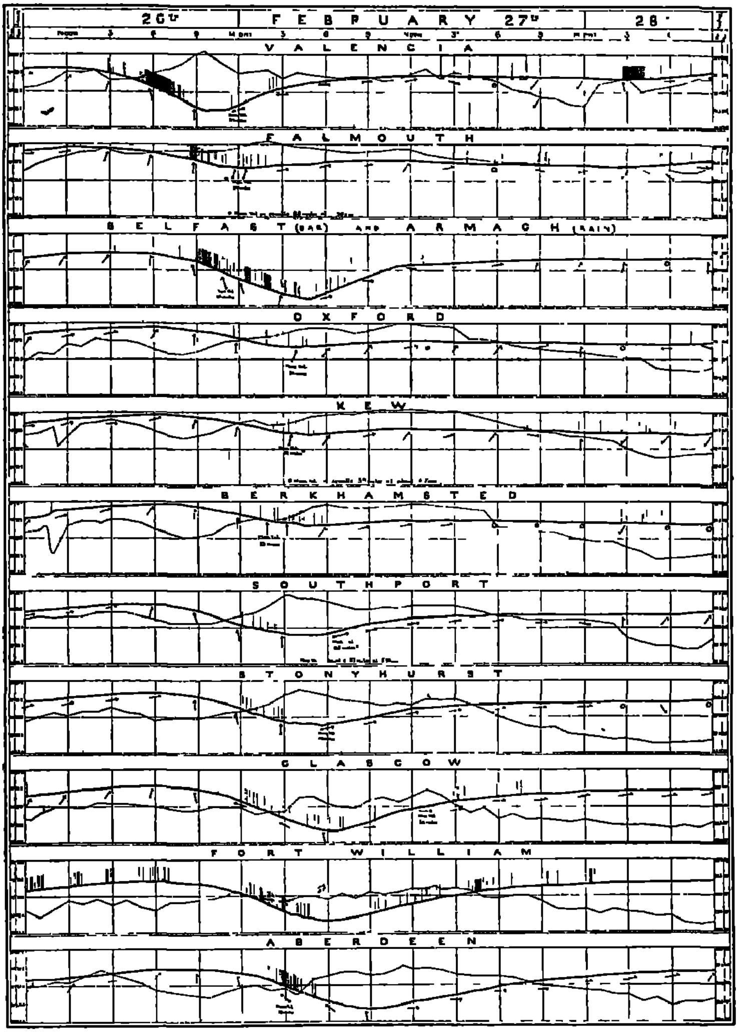
The statement that weather travels does not contradict common experience, for winds and clouds certainly travel, and anyone familiar with mountainous districts must have seen showers travelling. The travelling of weather which underlies modern forecasting is of a much more general

character, and it is only in rare instances that it can be treated with the precision that attaches to the motion of the wind, the clouds, or the passing shower. The travel of weather conditions was first recognised as an established principle in the case of tropical revolving storms, the study of which claimed particularly the interest of sailors. It was extended to the weather of temperate latitudes, chiefly on account of the impressive instance of a gale which passed along the south of Europe and did great damage to the French and English fleets in the Crimea, including the loss of the *Henri IV.* on November 14, 1854.

It was to a large extent upon this occurrence that Leverrier based his appeal to the Emperor Napoleon III. for the initiation of an international service of reports, which was the origin of our present system. By October, 1868, the travelling of weather across the Atlantic Ocean for the period March 13 to March 22, 1859, had been demonstrated by Dr. A. Buchan in a series of charts contributed to the "Journal of the Scottish Meteorological Society."

Since that time the principle of the travelling of weather conditions has been generally accepted, and I shall summarise this chapter by illustrating the effectiveness of synoptic charts for representing this aspect of the phenomena of weather. For this purpose I have chosen a special occasion, that of the gale of February 27, 1903. I will first point to the collection of records at a number of stations, any one of which will serve to represent what a single observer would have at his disposal if he wished. Fig. 13 shows the sequence of events between 9 a.m. on February 26 and 9 a.m. on February 28 at eleven stations, as recorded by autographic instruments. It will be seen that more or less similar phenomena occur at a number of the stations not simultaneously, but in succession. I show the representation of the same phenomena by means of synoptic charts by giving in Figs. 14 A.—F. the charts for 3 p.m., 6 p.m., 9 p.m. and midnight on February 26, and 9 a.m. and 6 p.m. on February 27. It may fairly be said

METEOROLOGICAL CHANGES AT SELECTED OBSERVATORIES DURING THE PASSAGE OF A CYCLONIC STORM, FEBRUARY, 1903.



The thick line represents the variation of barometric pressure.
The thin line represents the variation of air temperature.
The direction and force of the wind are represented by the arrows, with the addition of some incidental notes as to maximum values.
The occurrence of rainfall is represented by the vertical lines drawn upward from the barometric curve. A line is drawn for each hundredth of an inch.

FIG. 13.

FIG. 14A.

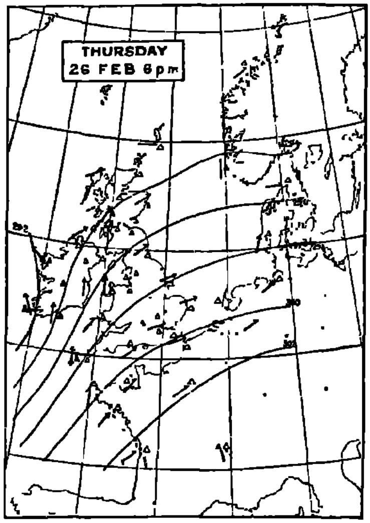


FIG. 14B.

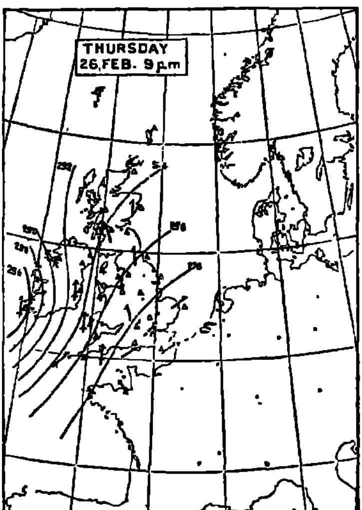


FIG. 14C.

FIGS. 14A—C.—Synoptic Charts for the Storm of February 26 to 27, 1903.

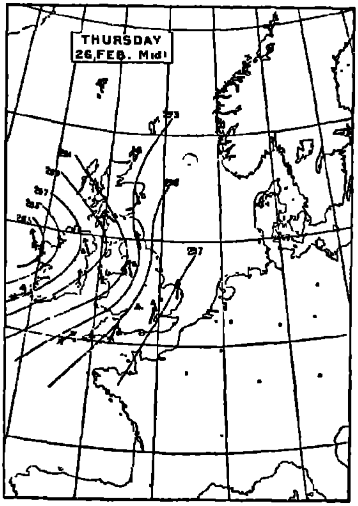


FIG. 14D.

FIG. 14E.

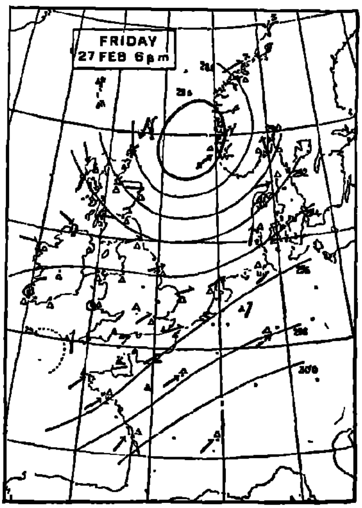


FIG. 14F.

FIG. 14D—F.—Synoptic Charts for the Storm of February 26 to 27, 1903 (*continued*).

that the representation by synoptic charts, though less detailed, is, for a rapid view, much more expressive.

CYCLONES AND ANTICYCLONES

Out of the study of synoptic charts there arose immediately a necessity for the classification of two characteristic types of closed isobars—those which were associated mainly with strong winds, and represented a circulation of air, more or less violent, round a low pressure centre, counter-clockwise, and those which were concerned mainly with light winds, and represented a gentle circulation of air clockwise round a centre of high pressure. The former was at once recognised as being similar in respect of the relation of wind and pressure to the tropical revolving storm, and the name "cyclone," which Piddington had coined [1] to represent the incurving counter-clockwise circulation common to all low pressure systems in the Northern hemisphere, came into general use. There is sometimes a tendency to regard the word as belonging naturally to the terminology of hurricanes, but it is not necessarily so.

For the region of light airs with a clockwise circulation, the name of "anticyclone" was coined by Sir Francis Galton, and introduced by him in his "Meteorographica" in 1861.[2] Since that time both names have become generally accepted to indicate the two chief groups in the classification of the shapes of isobars. We can best illustrate this classification by reproducing an example of each. Fig. 15 represents a cyclone over our islands and the North Sea at 8 a.m. on

[1] "The Sailors' Horn Book," 1848. chap. VIII.

[2] See "Proc. Roy. Soc.," 1863, p. 385. The following quotation explains Galton's point of view :—

"Most meteorologists are agreed that a circumscribed area of barometric depression is a locus of light ascending currents, and therefore of an indraught of surface winds which create a retrograde whirl (in our hemisphere). Consequently we ought to admit that a similar area of barometric elevation is a locus of dense descending current, and therefore of a dispersion of a cold dry atmosphere plunging from the higher regions upon the surface of the earth which, flowing away radially on all sides, becomes at length imbued with a lateral motion due to the above-mentioned cause, though acting in a different manner and in opposite directions."

CHART OF GALE IN WHICH THE S.S. "BERLIN" WAS WRECKED OFF THE HOOK OF HOLLAND, WEDNESDAY, 20TH FEBRUARY, 1907, 8h.

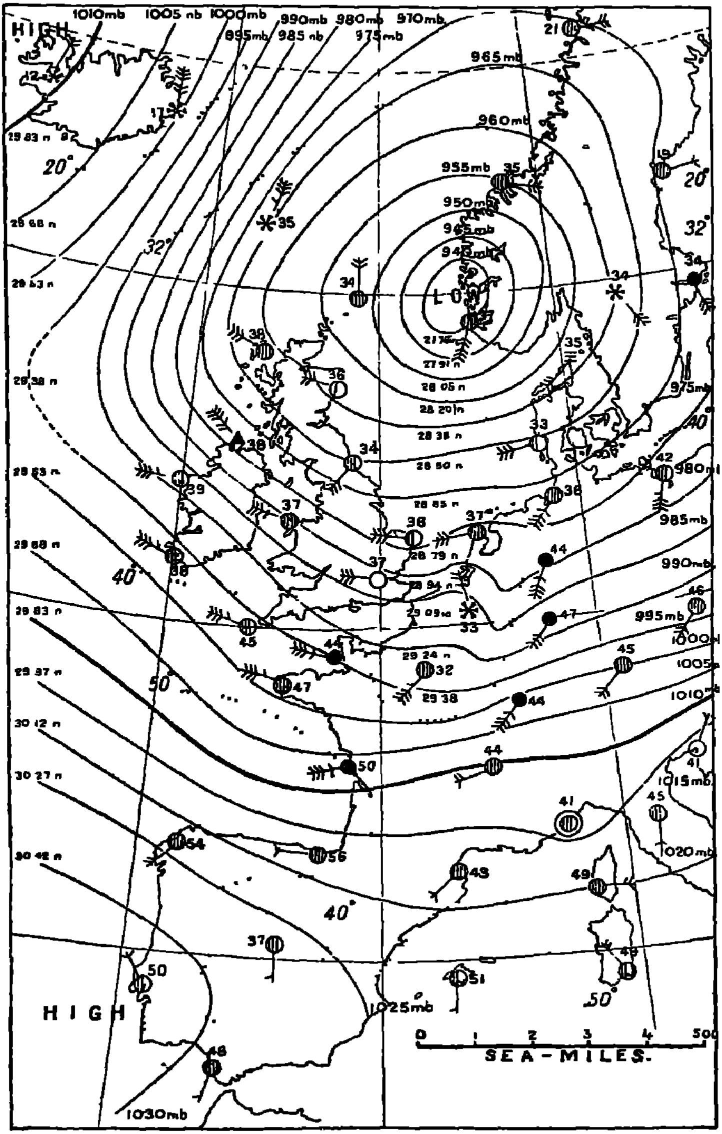
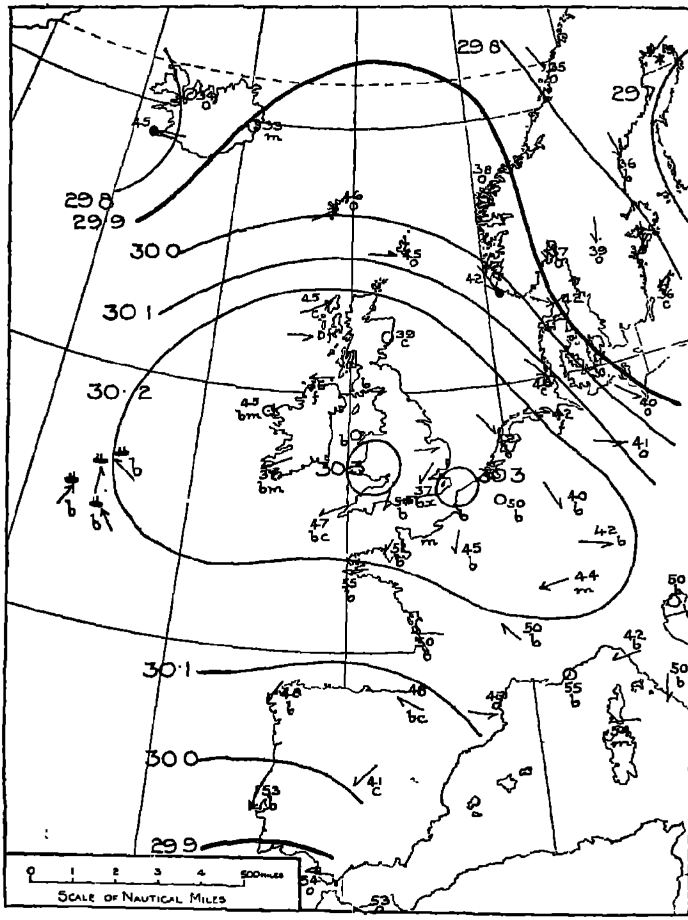


FIG 15 —Typical Cyclone

For the explanation of the symbols, see p 70

1909. April 9, 7 a.m.

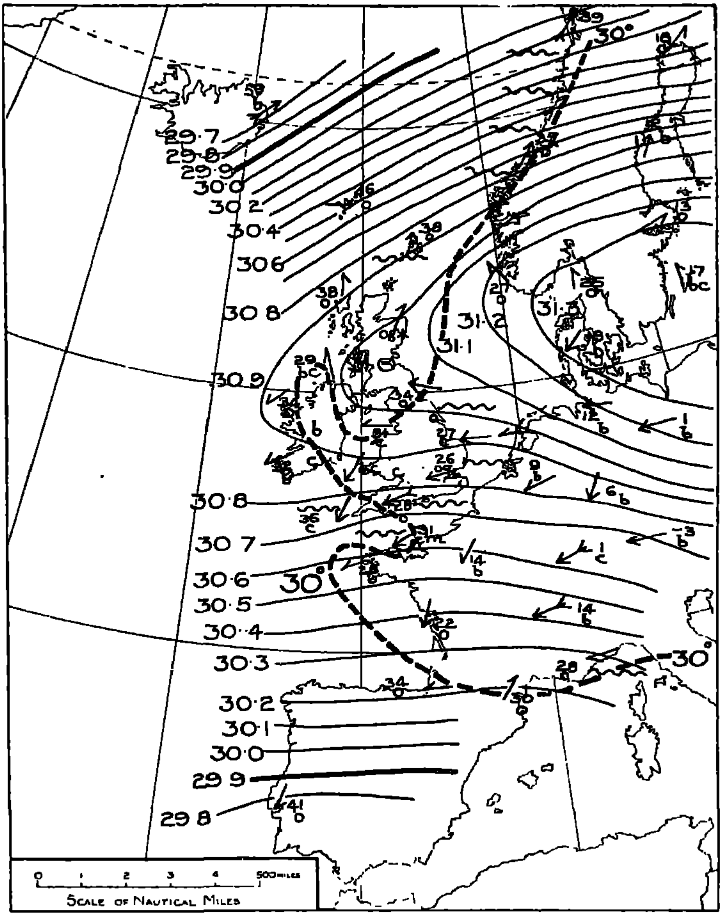


CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
29·7	1005·7	29·9	1012·5	30·1	1019·3
29·8	1009·1	30·0	1015·9	30·2	1022·7

FIG. 16.—Typical Anticyclone.
Note the local differences of temperature.

1907. January 23, 8 a.m.



CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
29·7	1005·7	30·3	1026·1	30·9	1046·4
29·8	1009·1	30·4	1029·4	31·0	1049·8
29·9	1012·5	30·5	1032·8	31·1	1053·1
30·0	1015·9	30·6	1036·2	31·2	1056·5
30·1	1019·3	30·7	1039·6	31·3	1059·9
30·2	1022·7	30·8	1043·0		

The dotted line is the isotherm of 30° F., or 272 t.

FIG. 17.—Western Section of the great winter Anticyclone of January, 1907.

February 20, 1907, and Fig. 16 represents the conditions of April 9, 1909, showing what would be called a normal anticyclone Fig. 17 shows the western portion of the great anticyclone of January 23 of the same year as the storm of February 20 (Fig. 15) when pressure was as low as 27·6 inches or 934·6 millibars. In Fig. 17 it reaches 31·3 inches or 1,060 millibars.

The first of these three charts represents the same occasion as the figure in the original edition, but it has been redrawn because as usual in all cases of very destructive gales there were data included in the working chart of the Office which were not shown in the Daily Weather Report of the day. The pressures have also been transformed into millibars and the chart exhibits a fine example of the type of map described on p. 17, which was in vogue from 1914 to 1919. The new symbolism is employed: circles for stations, cross-strokes for parts of the sky covered, a black dot for rain, a star for snow, a black triangle for hail, an arrow for wind with feathers to correspond with the Beaufort number. The wavy line for rough sea and the double wavy line for high sea have, however, been omitted for lack of space. The isobars drawn for steps of five millibars are represented by full lines and isotherms drawn for steps of 10° F. by dotted lines.

The charts which have been specially drawn for this edition, follow the same practice, but for those dated after January 1, 1920, the step of the isobars is four millibars instead of five.

The other two charts are the first examples of a large number specially prepared for this book in 1911 on the plan which was adopted for the Daily Weather Report, from January 1, 1911, in order to show pressure, wind, weather and temperature on a single map.

The ideas associated with cyclones and anticyclones are the practical basis of forecasting by means of synoptic charts, and a careful study of the details of the distribution of the meteorological elements in the regions covered by them is the first step towards comprehending the method.

CHAPTER IV

THE RELATION OF WIND TO BAROMETRIC PRESSURE[1]

In the consideration of a modern synoptic chart formed by the plotting of synchronous observations at a number of stations, as described in Chapter I., the isobaric lines are regarded as the most important feature. Taken together they give a view of the distribution of barometric pressure over the whole area. In modern practice it is usual to refer all the other phenomena which make up weather to the ascertained distribution of pressure. The process of forecasting practically begins with anticipating the changes of pressure which will take place within the interval for which the forecasts are made, in consequence of the travel of barometric conditions, with such modification of type as may be inferred from previous experience, and it is completed by assigning to the successive distributions of pressure thus anticipated the various conditions as regards wind, temperature, cloud or fog, rainfall or snowfall known to be generally associated with distributions of recognised type.

Of the various elements which can be related to the distribution of pressure, wind is in a class by itself, because its relation to the isobars is the most regular, and is nearly independent of the type of pressure-distribution.

BUYS BALLOT'S LAW

The general rule as regards the direction of the wind is known to meteorologists as Buys Ballot's law, because it was first clearly enunciated and insisted upon by Professor Buys Ballot, of Utrecht. Strange as it may seem to anyone familiar with weather maps to-day, its acceptance

[1] For fuller details of the treatment of this subject the reader may be referred to "Manual of Meteorology," Part IV., Cambridge University Press, 1919.

by meteorologists was a slow process. In this country Dr. A. Buchan and Mr. Joseph Baxendell were at first its chief advocates. It must be remembered that the distribution of pressure causes forces which push the air in the direction from high pressure to low, and perhaps a natural view is that the air moves in the direction in which the pressure is pushing it; but however natural it may be, it is erroneous. The working law may be thus enunciated for the northern hemisphere:—Stand with your back to the wind in the northern hemisphere and the barometer will be lower on your left hand than on your right. For the southern hemisphere the opposite is the case, and the law as applicable in that case is:—Stand with your back to the wind in the southern hemisphere and the barometer will be lower on your right hand than on your left.

In estimating the force and direction of the wind it is customary to face it, and the form of statement which is preferred by sailors is as follows:—If you stand facing the wind the lower pressure is on your right in the northern hemisphere and on your left in the southern hemisphere.

Applying this rule to a synchronous weather chart upon which isobars are drawn, it follows that the direction of the wind is more or less tangential to the isobars. Abercromby says, "In few cases is the wind exactly parallel to the isobars, but is inclined at an angle of about 30° or 40° to them." An arrow drawn on a chart to indicate the direction of the wind in the northern hemisphere will therefore have the low pressure on the left hand side of the direction in which the air is moving, and the direction of the wind will deviate from the direction of the isobar generally to the extent of 30° or 40° towards the low pressure side.

We may illustrate this rule by three cases:—Fig. 18, for straight isobars; Fig. 19, for the isobars of a cyclonic depression which are concave to a centre of low pressure; and Fig. 20, for the isobars of an anticyclone which are concave towards a centre of high pressure. Of the two arrows drawn in each system of isobars one is *tangential* to the isobar and the

other inclined at 45° to the direction of the isobar, which it crosses towards the low pressure side. According to Abercromby the wind will seldom be found in the tangential direction indicated by A, but most frequently somewhere

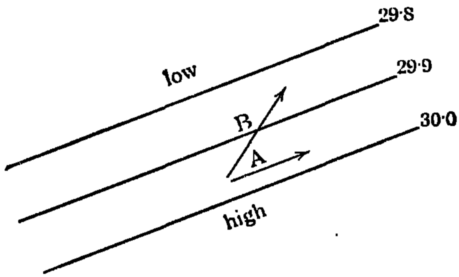


FIG. 18.—Relation of Wind Direction to Straight Isobars.

between the direction indicated by A and that indicated by B. Thus the motion of the air sometimes consists of pure tangential motion along the isobars, but most frequently the tangential motion is compounded with a motion across the

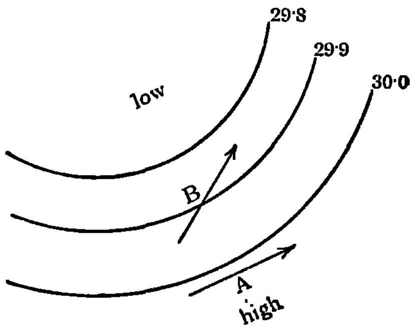


FIG. 19.—Relation of Wind-Direction to Cyclonic Isobars.

isobars from high to low. If the inclination of the wind to the isobars were 45° the motion along the isobars and the motion across the isobars from high to low would be equal. We may therefore conclude from Abercromby's statement that the component of the motion across the isobars is generally less than that along the isobars, and there are cases in which there is no motion at all across the isobars. The

between the direction of the isobar and the direction of the wind has been called by Clement Ley the inclination of the wind, and the complementary angle, namely, that between the wind and the line of gradient, which is normal to the isobar, is called the deviation of the wind (Ablenkungswinkel). See Hann, "Meteorologie" (Edition 1906), p. 371. Much attention has been paid to the magnitude of these angles for different meteorological conditions, and average values for different winds have been taken out for different localities. I do not propose to follow the discussion of these values in detail, because the difference of inclination on different

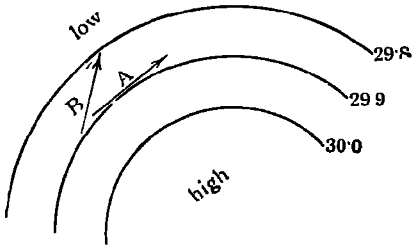


FIG. 20.—Relation of Wind-Direction to Anticyclonic Isobars.

occasions may be due to a variety of causes which cannot be dealt with by the method of averages.

Among the causes which may affect the angle of inclination as measured we may note the following: First, the pressure for which the isobar is drawn is reduced to sea level, but there is no corresponding reduction for the wind, so that on the chart the wind is compared with a pressure distribution for a different level. Secondly, the difference of exposure of the different stations of observation is a very important consideration as concerning the wind, but of very little importance as concerns the pressure.[1] The frictional effect of the ground

[1] The pressure at the surface in lbs. per square foot may be regarded as the weight of a vertical column of air one square foot in section extending from the surface to the outer confines of the atmosphere. The weight of the column will depend upon the density of the air of which it is formed as well as upon the height. The density of air is subject to variation on account of changes in its composition, its pressure, its temperature, and its humidity.

and of the obstacles upon it is an uncertain element for every station. Observations with kites show that above the surface the inclination of the wind to the isobar becomes less, and about $22\frac{1}{2}^\circ$ of veer from the surface to the upper air may be allowed on this account in ordinary winds. (See Gold and Harwood, B. A. Report, 1909.) Thirdly, the drawing of isobars upon an isochronous chart is not yet carried to so high a degree of refinement as the local measurement of the direction of the wind. An inspection of the charts of a self-recording barometer will show sometimes quite noticeable variations in the pressure which are not represented in the synchronous charts, and are therefore neglected in the conspectus of the pressure distribution which a synoptic chart provides. The charts are prepared from observations at places a great distance apart, and the tendency is to round off or smooth the isobars. The true direction of the isobar in any particular locality is often altered in that way. Sudden changes of wind are often related to equally sudden changes in the direction of isobars (see Chapter XI.), but as a rule the changes are smoothed out on the map, because, for one reason, there is generally no means of knowing the precise locality at which the sudden change occurs.

On most days, and in particular on every sunny day, there is probably a slight difference of pressure between sea and land which could only be shown by refined measurements of pressure in the immediate neighbourhood. It may extend over only a few miles and be merely of the order of a hundredth of an inch, but the local wind will be governed by it though the isobar on the chart is not drawn to show any dislocation on passing from sea to shore. An example of such an occasion is quoted in "Barometric Gradient and Wind Force" (M.O. publication No. 190, p. 9).

In the British Isles we are very favourably situated for getting precise information about pressure from stations not far apart, and the exposure of many of our coast stations is very free, so that little correction of wind-direction is necessary

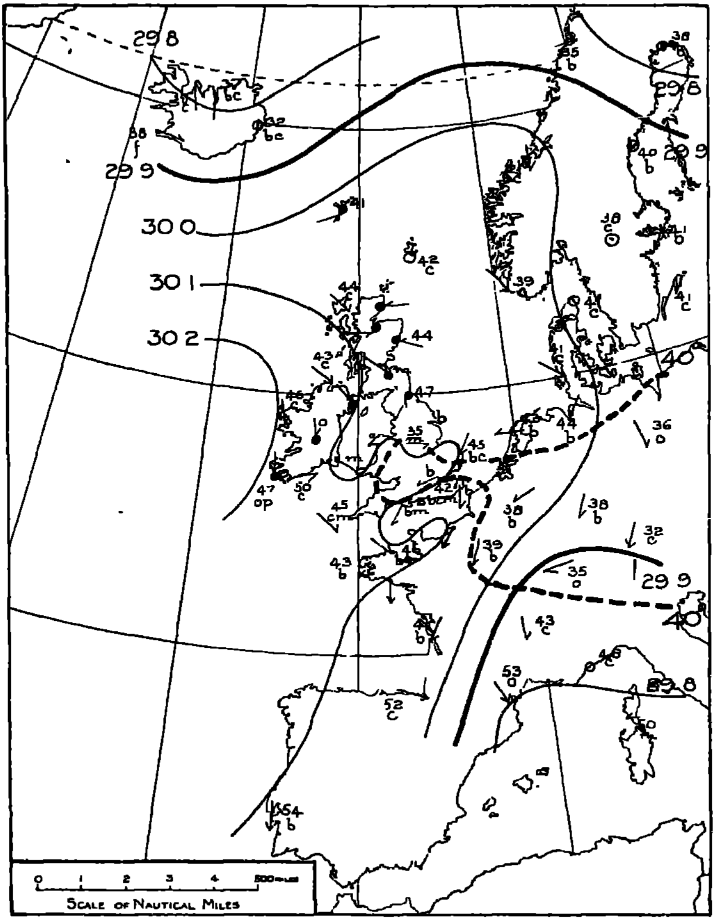
in order to make allowance for the surface disturbance. Experience with our maps goes to show that the more carefully the details of the isobars are elaborated the more closely are the directions of the wind in different parts of the country in accord with the direction of the isobars, and cases of the wind being actually tangential to the isobars are much more frequent than would appear at first sight.

An examination of the charts of the Daily Weather Report will be sufficient to satisfy anyone as to the general appropriateness of the statement of Buys Ballot's law. I give one example (Fig. 21) of a special case of isobars with winds of no great strength in which the run of the isobar for 30·1 inches is clearly followed by the winds with remarkable fidelity. The reader should notice also in this case, by tracing the line of the isotherm for 40°, which represents an intrusion of cold air from the east, how the outlier of high pressure protruding from the western anticyclone is associated with the cold protuberance, thus indicating a tendency for cold surface-air to be associated with high pressure. The tendency may be regarded as general, but there are many causes which interfere with its application (Chapter XII.).

BAROMETRIC GRADIENT AND WIND FORCE

Let us now enter upon the consideration of the force or velocity of the wind in relation to the pressure distribution. For this purpose it is necessary to introduce a definition of the barometric gradient. This is, briefly, the rate of fall of pressure along the line of steepest downward slope. We are using here for purposes of analogy the terminology of an orographical map with contour lines. We have first to find the line of steepest slope to lower pressures. In the case of parallel isobars (Fig. 18, p. 73), the line must clearly be drawn at right angles to the isobars and towards the low pressure. If the isobars are curved (Fig. 22) we draw in a corresponding way the gradient line "normal," or at right angles to the tangent, to the isobaric line at the point where we want to find

1908. April 9, 8 a.m.



CONVERSION TABLE.

In.		Mb.	In.		Mb.	In.		Mb.
29·8	.	1009·1	30·0	.	1015·9	30·2	.	1022·7
29·9	.	1012·5	30·1	.	1019·3			

The dotted line is the isotherm of 40° F. (277·4 t.).

FIG. 21.—Chart to show the Relation between the Wind Direction and Pressure along the Isobar of 30·1 inches.

the pressure-gradient, and take the direction towards the low pressure. Along that line—the gradient line—we must measure the rate of fall of pressure. It is usual to express the rate of fall by quoting the fall of pressure in hundredths of an inch for a quarter of a geographical degree, or fifteen nautical miles. In practice we have to measure the distance along the gradient line corresponding with the interval of pressure between two isobars and compute the pressure-gradient from the measured distance. Thus, to find the gradient at the point X for a map on

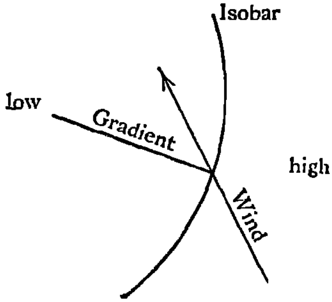


FIG. 22.—Relation of Wind Direction to Isobar and Gradient.

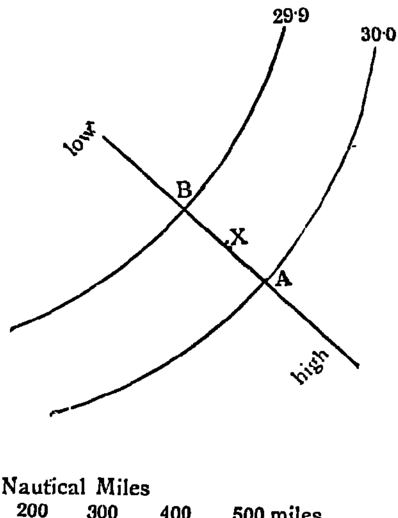


FIG. 23.—Computation of the Gradient-wind.

which the isobars of 30·0 inches and 29·9 inches are represented, in Fig. 23, we take the line A B, normal to the pair of isobars,

measure the distance between the consecutive isobars (140 miles according to the scale), then the fall of pressure in fifteen nautical miles is $\frac{15}{140} \times \cdot 1$, or $\cdot 0107$ inch. Hence the gradient is ·0107 inch of mercury pressure per fifteen nautical miles.

In the figure I have placed the position of X very favourably for getting a good measure of the gradient. It is just midway between two isobars which are reasonably parallel. This is by no means always the case in determining gradients on a map. Sometimes the point is close to one isobar which is not equi-distant from those on either side, and sometimes, for want of data, no isobar can be drawn on one side of the point. Thus in determining the gradient a good deal may have to be left to the judgment of the operator, but it is not necessary to enter here into the details to be followed in obtaining the best result in difficult cases which sometimes arise. I will confine myself to those cases in which the measurement is reasonably free from doubt. Since what we have to measure on the map is the distance between consecutive isobars, it is clear that we may use the distance between isobars as the inverse of barometric gradient without going through the arithmetical computation of the gradient every time. It will be understood that when the isobars are close together the gradient is large, when they are wide apart the gradient is small, and in general terms the crowding together of isobars is an indication of increased gradient.

We have already seen that, with an allowance for inclination, the direction of the isobars represents the direction of the wind; the next step is to realise that the closeness of the isobars is a good indication of the velocity of the wind.

In illustration of this general rule Abercromby quotes a table of mean wind velocity for different gradients at Kew, prepared by Whipple in 1882 from observations at Kew Observatory. I extract the following:—

Gradient per fifteen Nautical Miles.	Distance between consecutive isobars in the larger Chart of the Daily Weather Report.	Wind Velocity in Miles per Hour.
·002 inches	2·5 inches	5·0
·010 "	·5 "	9·2
·020 "	·25 "	16·5
·030 "	·17 "	25·5

For certain reasons, to which I will refer later, there are difficulties about accepting a table of this kind as a full representation of the relation of gradient to wind. The determination of small gradients from an ordinary map is liable to considerable errors, and this may be borne in mind when it is noticed that the proportionality of wind-velocity to gradient is very nearly approached for the two highest gradients in the table, but it does not hold for the lower numbers. The table shows clearly enough, however, that the greater the gradient, the greater is the velocity of the wind recorded at the observatory, and this relation is generally true for all observatories that are not close to the equator.

Innumerable examples of this general principle occur in practice and any series of weather maps will serve to illustrate it.

A law of this kind which is approximately true for individual cases is equally approximately true for mean values, so that a map which shows the mean gradients over the world will also give us approximate information about the mean winds of the world. I shall illustrate this most important meteorological law by reference to the charts of pressure and winds for the globe for the months of January and July, taken from the "Barometer Manual for the Use of Seamen," already given in Chapter III. (Figs. 9 and 10). In these charts, the results for pressure and wind have been determined quite independently, but the explanations of the mode of representation given on the charts are sufficient to enable anyone looking into the matter to see with what fidelity the

distribution of isobars gives the recorded strength of the winds.

DYNAMICAL EXPLANATION OF THE RELATION BETWEEN PRESSURE AND WIND

Regarded as an empirical law, the relation between pressure and wind is the most conspicuous achievement of modern meteorology, and its explanation upon dynamical principles makes it still more interesting.

I shall endeavour to give a general account of the explanation, because it enables us to look at the relation from a standpoint which is of great importance in practical meteorology. The most striking feature to be noticed is that the direction of the wind is along the isobars, whereas the pressure is pushing the air in the direction of the gradient, that is, at right angles to the isobars. Now it is a common dynamical observation that so long as a body can keep moving at right angles to the force which is acting upon it, it will change its direction, but will not alter its speed. A pendulum-bob P held by a string PQ swinging in a horizontal circle is a very good illustration (Fig. 24). If we stop the bob P, it falls at once to the centre O. So long as it keeps moving with the same speed it will describe the circle, but not yield to the force. If we increase the speed, it will want a larger circle, and require a greater force, but in the absence of any disturbance of that kind, it keeps on its circular path. The friction of the air gradually retards it, so ultimately, in practice, it finds the centre.

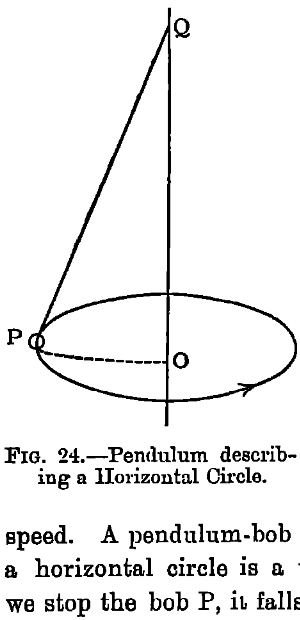


FIG. 24.—Pendulum describing a Horizontal Circle.

In steady motion the force F must be so adjusted that

$F = mv^2/r$, or $v^2/r = F/m$, where v is the speed, r the radius of the circle, and m the mass of the moving body.

It is the same with the air: if it revolves in a circle about a point with a proper velocity, it can support an adjusted pressure without any other result than a change of direction. Such rotations of the air are exhibited in nature on the large scale in tropical revolving storms. The appropriate equation for air moving in a "small circle" on the earth's surface of angular radius α is $V^2 \cot \alpha / E = b/\rho$, where V is the velocity, E the radius of the earth, b the necessary pressure gradient, and ρ the density of the air.

But there is another rotation to which moving air has in like manner to accommodate itself, and that is the rotation of the earth over which it moves. Here we have a different view of a similar experiment.

If the air is moved by any cause whatever, and left to itself, it will not keep in what corresponds with the straight line of its motion on the earth's surface, that is a great circle, because the earth will rotate underneath it. For the same reason a gunshot deviates to the right in the northern hemisphere, because the earth rotates underneath it from right to left or counterclockwise. If you wish to keep a gunshot or air in its line of motion along a great circle on the earth, you must push it while it is moving so as to compensate for the earth's rotation.

According to the theory originally expounded by Ferrel in America and by Guldberg and Mohn in Europe the effect of the earth's rotation is the same as if every portion of the moving air were subject to a force across its path from left to right equal to $2\omega\rho V \sin \phi$, where ω is the angular velocity of the earth, ϕ the latitude of the place, V the velocity of the air, and ρ its density; so, for motion in a great circle it must be pushed in the opposite direction by a force across the path to balance the deviating effect of the earth's rotation. The pressure distribution will supply the necessary force if its gradient b is of the right value; hence the equation

$$b = 2\omega V \rho \sin \phi$$

gives us the condition under which the air will keep exactly straight, that is, will describe a straight isobar along a great circle.

This is obviously a verv delicate adjustment. If the gradient b becomes too great the air is pushed away to the left and gets up speed until the increase of V brings up the balance again. If V gets smaller for some reason, as for example by friction, the balance is disturbed because V is not now big enough. In favourable circumstances, by a proper adjustment of pressure on either side, an air current can be steered the world over.

In the second part of "The Life History of Surface Air Currents," (M.O. publication No. 174), the paths of air for long stretches over the Atlantic have been traced, and it is interesting to notice how the steering is performed by the adjustment of pressure on the two sides. (See Chapter IX.)

But generally in meteorology we find in combination with this directive action of pressure due to the rotation of the earth, the centrifugal action round a centre of low or high pressure. In such cases we have

$$\frac{b}{\rho} = 2\omega V \sin\phi + \frac{V^2}{E} \cot\alpha,$$

when the pressure required to keep the motion in a circle is in the same direction as that required to compensate for the rotation of the earth, *i.e.*, for a cyclonic circulation; and

$$\frac{b}{\rho} = 2\omega V \sin\phi - \frac{V^2}{E} \cot\alpha,$$

when the two components of pressure are opposite to each other.

The underlying principle of these equations is that the pressure gradient is just balanced by appropriate motion of the air. There is every reason to think that that principle, and the equations which represent it, give us the explanation of the relation of the motion of air to every ordinary distribution of pressure.

An investigation of the actual paths of air in travelling

depressions in "The Life History of Surface Air Currents" shows that in all ordinary cases the changes in the velocity of the wind as it travels are very slow. It takes twelve hours for air to circumnavigate the centre of a depression even in a fast travelling storm, when the path of the air goes close to the centre, and the change in velocity during the process is, dynamically speaking, negligible. Hence the assumption of the balancing of the pressure by the motion is well supported. Moreover, the calculation gives results which agree very closely with practice if one makes allowance for surface friction. From kite observations, it appears that at 1,500 feet above the surface the agreement is generally very close.

Moreover, the second equation, which is applicable to anticyclones, explains why such small velocities are to be found in the central regions of an anticyclone. It will be seen that the equation is a quadratic for determining V. When ϕ and ρ are known the roots of the equation become imaginary if b exceeds a certain value.

The equations explain further why a single table of average correspondence between gradient and wind force is not adequate for all cases, because the formula applicable is different according as the path which the air follows is straight or curved. Separate tables are required for straight isobars and for curved paths of different curvature.

The determination of the curvature of the path of the air is not possible from a single map. We require to trace the previous history of the air. For the present, therefore, we shall confine ourselves to the calculation of gradient wind for straight isobars. The wind so calculated is called the "geostrophic wind."

The following table shows the relation between the distance of separation of the isobars, and the computed geostrophic wind velocity for selected pressures and temperatures of the air in latitude 53°. This table serves to give an approximate value of the geostrophic wind in our islands. A separate table would be required for latitudes further south than 48° or further north than 58°.

TABLE SHOWING DISTANCES APART IN NAUTICAL MILES OF CONSECUTIVE $\frac{1}{10}$-INCH ISOBARS IN LATITUDE 53°, CORRESPONDING WITH STATED GEOSTROPHIC WIND VELOCITIES, PRESSURES AND TEMPERATURES.

Beaufort Number.	Geostrophic Wind Velocity. Miles per Hour.	Metres per Second.	Feet per Second.	Pressure and Temperature.						
				in. °F. 31 28 30 13 — — — —	in. °F. 31 44 30 27 29 11 — —	in. °F. 31 60 30 43 29 26 28 10	in. °F. 31 77 30 60 29 43 28 25	in. °F. — — 30 78 29 60 28 42	in. °F. — — 30 97 29 79 28 60	in. °F. — — — — 29 99 28 79
				Distances apart in Nautical Miles of Consecutive $\frac{1}{10}$-inch Isobars.						
2	5	2·2	7·3	520	540	560	580	600	620	640
3	10	4·5	14·7	260	270	280	290	300	310	320
4	15	6·7	22·0	170	180	190	190	200	210	210
5	20	8·9	29·3	130	140	140	140	150	150	160
6	25	11·2	36·7	100	110	110	120	120	120	130
	30	13·4	44·0	87	90	93	97	100	100	110
7	35	15·7	51·3	75	77	80	83	85	88	92
8	40	17·9	58·7	66	68	70	72	75	77	80
	45	20·1	66·0	58	60	62	64	66	69	71
9	50	22·4	73·3	52	54	56	58	60	62	64
10	55	24·6	80·7	48	49	51	53	54	56	58
	60	26·8	88·0	44	45	47	48	50	52	54
11	65	29·1	95·3	40	42	43	44	46	48	49
	70	31·3	102·7	38	39	40	41	43	44	46
	75	33·5	110·0	35	36	37	39	40	41	43
12	80	35·8	117·3	33	34	35	36	37	39	40
	85	38·0	124·7	31	32	33	34	35	36	38
	90	40·2	132·0	29	30	31	32	33	34	36
	95	42·5	139·3	28	28	29	30	31	33	34
	100	44·7	146·7	26	27	28	29	30	31	32
	110	49·2	161·3	24	25	25	26	27	28	29
	120	53·6	176·0	22	23	23	24	25	26	27
	130	58·1	190·7	20	21	21	22	23	24	25
	140	62·6	205·3	19	19	20	21	21	22	23

Correction for an increase of 1° F. in temperature.—Add $\frac{1}{3}$ per cent. to the velocity.

Correction for an increase of 0·1-inch in pressure —Subtract $\frac{1}{3}$ per cent. from the velocity.

Correction for an increase of 1° in latitude.—Subtract 1 per cent. from the velocity.

*** The values in the table are computed for air moving along a great circle. The direction of the geostrophic wind is along the isobars with the low pressure to the left in the northern hemisphere.

This table can be used to compute the geostrophic wind from a chart of isobars, and the computation presents no difficulty if the chart carries a scale of nautical miles. It is a very useful meteorological exercise to compare the geostrophic wind obtained in this manner with the wind noted by the observer and charted on the map. The comparison should be made both as regards direction and speed. In order to facilitate the comparison when the observed wind is given on the Beaufort scale, the first column of the table may be used. It gives the Beaufort number which would be used to represent the wind velocity as given in miles per hour in the second column. When the velocity falls between consecutive numbers in the second column it may be necessary to refer to the conversion table of p. 70, in order to decide which Beaufort number to use.

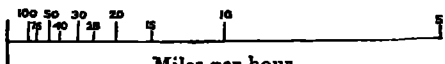
The introduction of C.G.S. units for the measurement of pressure has introduced some changes in ordinary practice which ought to be noticed here. In the first place a distinction has been drawn between that part of the barometric gradient which depends upon the rotation of the earth and that part which depends upon the curvature of the path, and separate names have been given. The part which depends upon the rotation of the earth and is expressed by the formula $2\omega V \sin\phi$ is the *geostrophic* component and the part which depends upon the curvature of the path and is expressed by the formula $V^2 \cot \alpha / E$ is called the *cyclostrophic* component. Further, the wind, which is computed from the gradient for straight isobars, or neglecting the component of pressure due to the curvature of the path, is called, as we have seen, the *geostrophic* wind.

The diagrams of Figs. 18, 19, 20, 22, 23 apply equally to the computation of the wind from the distribution of pressure expressed in millibars, and we may suppose the numerical indications assigned to the isobars to be suitably altered and to become, for example, 1,010, 1,012, 1,014, instead of 29·8, 29·9, 30·0 in Figs. 18, 19, 20 and 23. The measurement of gradient must also

be extended to include the expression of gradients in millibars per 100 kilometres or some other distance. We also require a new table for C.G.S. values in place of the table of p. 85. But, as a matter of fact, gradients are seldom measured in actual practice. It has been found much more convenient to use a scale which could be laid on the map and which would give directly the reading of the velocity in metres per second, or in miles per hour by the formula $V = b/(2\omega\rho \sin \phi)$, according to the graduation of the scale. Such a scale is really applicable only for one pressure and one temperature because the density of the air, represented by ρ in the formula is dependent upon the values of those elements but a correction can easily be made for the departure of the density from the normal values for which the scale is constructed, although generally, in view of the crudeness of the measure of the gradient, the application of any correction is hardly worth while.

GEOSTROPHIC WIND SCALE FOR

4 mb isobars on 1 : 2 × 10^7 Charts.
or 2 mb ,, ,, 1 : 10^7 ,,
or 1 mb ,, ,, 1 : 5 × 10^6 .



Miles per hour.

FIG 25.

We give here (Fig. 25) a reproduction of the scale which was introduced into the Meteorological Office as a scale printed on transparent material for use with the working charts because it is also applicable to the charts of the British Section and the International Section of the Daily Weather Report. It expresses the velocities in miles per hour, and we have therefore prepared a modification of the scale (Fig. 26) which gives the velocities in metres per second.

Furthermore, for easy computation of geostrophic winds from the maps reproduced in this book a scale of nautical miles was added in each map with which the table of p. 85 could be used. A scale of geostrophic winds is, however, so much more handy

for this purpose that we include here Fig. 27, a suitable scale for isobars drawn for intervals of one-tenth of an inch, and Fig. 28, another drawn for intervals of 4 millibars on the scale of our maps. The reader is recommended to prepare for himself on transparent paper a copy of the scale which he can use to deter-

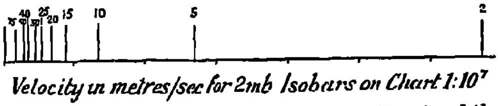


FIG. 26.—Geostrophic Wind Scale for the Charts of the Daily Weather Report.

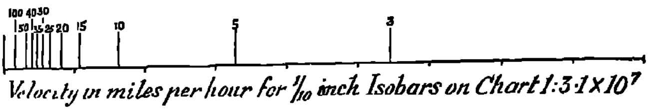


FIG. 27.—Geostrophic Wind Scale in Miles per Hour for the Weather Charts in Inches, as reproduced in this book.

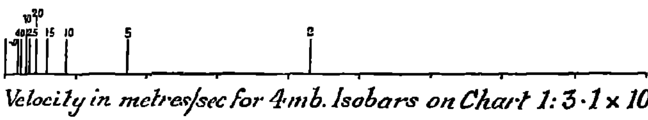


FIG. 28.—Geostrophic Wind Scale for the Weather Charts in Millibars as reproduced in this book.

mine the geostrophic wind on the standard maps of North-Western Europe which appear in this book.

Recently at the Meteorological Office the comparison of the gradient or, generally speaking, the geostrophic winds, with the winds recorded on anemometers, or estimated on the Beaufort scale, has been made for a number of observatories and stations.

It is evident from the results that so far as anemometers are concerned a good deal depends upon the exposure of the station. The best illustration of this conclusion is furnished by the records for Falmouth where the Office maintains a cup anemometer at the observatory in the town and a pressure tube anemometer on the tower of Pendennis Castle, which crowns an isolated hill at the entrance to the harbour. The average results for the speed of the wind are represented in the

diagram (Fig. 29). Taking the radius of the outside circle as representing the velocity of the geostrophic wind, the first of the two inner curves represents the corresponding velocity as recorded at Pendennis Castle, and the second of the two the velocity at Falmouth Observatory. The variation of direction is not shown. It is plain from the diagram that the records from Pendennis show about half the geostrophic wind for air coming from the west. The agreement between observed and geostrophic wind is better for air coming from the eastern quadrants, and reaches between 80 per cent. and 90 per cent. for the gradient direction due south, that is, when theoretically the wind would be due east. For the observatory we get a curve not very different from a circle the radius of which is about one-third of that corresponding with the geostrophic wind.

It will be understood from what has been said that the relation between the observed surface wind and the barometric gradient is complicated partly by meteorological and partly by local causes which include surface friction. As one rises above the surface the effect of friction is reduced. Generally speaking the velocity of the wind increases and veers. A closer approximation to the gradient wind is the result.

Hence, in dealing with this part of the subject we have to take into account the changes which take place as we pass to higher regions. In many practical ways the region of transition just above the surface is a very important one. It is in fact the region of greatest interest to the aeronaut because it is the region of his starting and landing. At present we know that the actual velocity of the moving upper air agrees much more closely with the gradient velocity as computed from the surface pressure than does the surface wind, and, for the time being, we may regard the gradient-wind as the best estimate which we can give of the actual wind at, say, 1,500 feet above the surface. Beyond that height changes of gradient may occur in consequence of differences of density of the lower layers. It becomes a matter of great importance

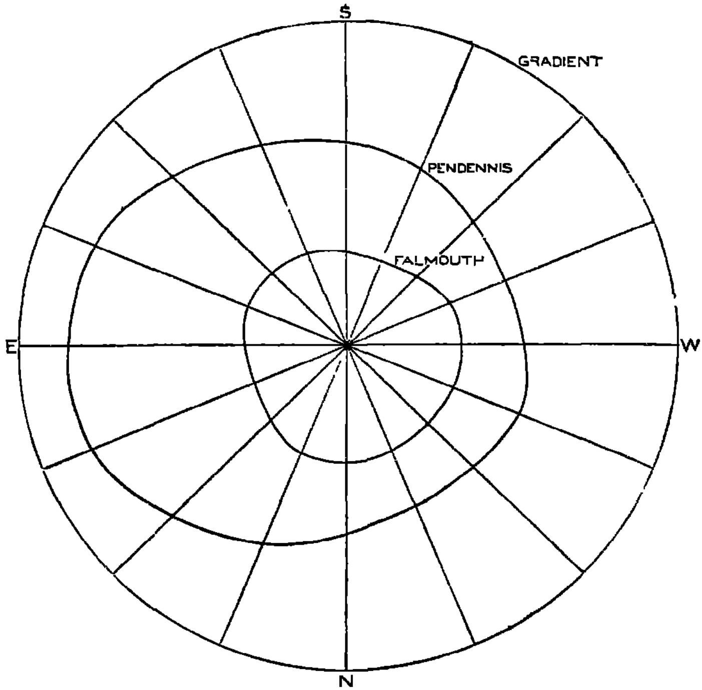


FIG. 29.—Geostrophic Wind Velocity compared with Local Wind Velocity at Pendennis Castle and Falmouth Observatory.

The points N, S, E, W, correspond with the directions of the geostrophic wind. Assuming the outside circle to represent the geostrophic velocity, the inner curves represent the corresponding wind velocity for the various points of the compass as registered at Pendennis Castle and at Falmouth Observatory, at 7 a.m., in the year December, 1908, to November, 1909.

to aeronauts to form some idea of the mode of transition from the surface wind as registered by an anemometer near the ground to the gradient wind From the study of a large number of observations with pilot balloons and kites, it appears that a fair working rule may be got by assuming that at any station the wind increases as the height of the point of observation above sea level increases, and proportionately to that height, and that the gradient velocity may be regarded as the limiting velocity for what may be called the surface

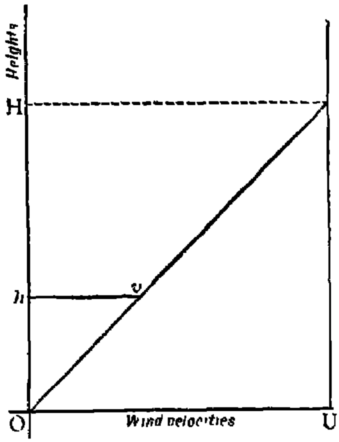


FIG. 30.—Diagram representing the probable Variation of Wind Velocity with Height between the Anemometer Height h, and the Position H where the Gradient-wind for Surface Isobars is reached

distribution of pressure It follows that we may have the following rough working rule for obtaining the change of velocity above the surface. Let Oh (Fig. 30) be the height of the anemometer *above sea level*. OU the gradient velocity, hv the velocity recorded by the anemometer. Draw the line UV parallel to the axis Oh. Join Ov and produce it to meet the vertical UV in V. Then the velocity at any height above h will be given by the distance from OH of the line vV, and the height at which the gradient velocity will be reached is represented by OH, where H is the height of the point V. For further information on this point the memorandum by the author on

Wind Structure in the report of the Advisory Committee for Aeronautics for the year 1909-10 may be consulted.

THE EFFECT OF TURBULENCE OR EDDY-MOTION ON THE VELOCITY OF WIND NEAR THE GROUND

When the last paragraph was written there was not much to go upon in order to make a rational, as distinguished from an empirical, formula, for the variation of wind with height above the ground. The most noteworthy point about the subject was that for practical purposes wind measurements had to be taken from anemometers which were exposed some on buildings, some on masts rising from the ground, with no regulation as to the height of the vane or the cups, and no knowledge of the effect of buildings upon the records. At many stations the wind was merely an estimate on the Beaufort scale for which a table of equivalents in velocity had recently been prepared. On the other hand, for reasons already given, the computation of the wind from the distribution of pressure could only be regarded as a very rough approximation.

An examination of a large number of graphs of wind-velocity and height, made from the results of observations with pilot-balloons at Ditcham Park and with kites at Pyrton Hill and at Glossop Moor, showed that the tails of the graphs pointed directly to the " origin " of zero velocity at sea-level. The rule suggested was put forward as an empirical method of giving a sufficient answer to a practical question, and it seemed probable that when applied to a measure of wind for an exposure like that of a flat shore, as compared with the inland exposures about 500 feet above sea-level, the rule would give a more speedy approach to the geostrophic wind; probably with some justification.[1]

But now the situation has changed. Not only has E. H. Chapman, in a publication of the Meteorological Office,[2] examined the question from the statistical aspect and given a formula, $V = a \log H + b$, for the variation of wind with height above

[1] See M.O. 220d, 1919. C. J. P. Cave and J. S. Dines. " Soundings with Pilot-Balloons in the Isles of Scilly, November and December, 1911."

[2] *Professional Note*, No. 6, M.O. 232 f.

the ground, which is certainly more rational than the rule of variation directly proportional to height, but the whole subject of the effect of the friction of the ground upon the velocity of the wind in relation to the geostrophic wind has been examined in connection with the theory of turbulence, or of eddy-motion of the air, by G. I. Taylor. The conclusion which that author draws is that there is a simple relation between the ratio of the surface-wind W. to the geostrophic wind G and the angle of deviation of the direction of the surface-wind from the direction of the isobar towards the low pressure. Calling this angle of incurvature a Taylor's formula is

$$W/G = \cos a - \sin a.$$

The change of velocity with height follows an exponential law.

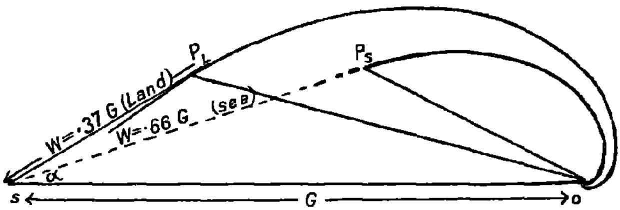


FIG. 31.—Diagram showing the Relation of the Sea Wind and the Land Wind which would correspond with a Specified Geostrophic Wind according to the Theory of the Effect of Eddy-motion upon an Air Current.

F. J. W. Whipple [1] has pointed out that the changes are indicated by successive points on an equiangular spiral of which the extremity of the line representing the geostrophic wind is the pole (Fig. 31).

SO is the geostrophic wind. OP_L is the spiral which defines the effect at successive heights of the friction of the land. SP_L represents the surface wind over land with W=·37 G. OP_S is the spiral which defines the effect of the friction of the sea. SP_S represents the surface wind over the sea where W = ·66 G.

But the calculations depend upon assumptions as to the uniformity of density, eddy-viscosity and pressure-gradient that may not always be justified.

[1] "Q. J. R. Met. Soc.," vol. 46, p. 39; D. Brunt, *ibid.*, p. 175.

These calculations are derived from the discussion of the effect of eddy-motion in the atmosphere which opens up a new and interesting department of meteorological theory. It deals with the gradual ascent of air in consequence of the development of eddies which may be studied, for example, in the gradual spreading out of the smoke trail of a chimney or a steamer funnel in a passing wind which is full of incomplete eddies, or on a much vaster scale in the carrying up of sand in a simoon or desert sandstorm. The same phenomena are exhibited, on the other hand, in the inequalities shown in the direction and velocity of the wind as recorded on the pressure tube anemograph, on which the deviations of the wind from its mean value are roughly proportional to its mean speed. They are also probably exhibited in the formation of all kinds of cloud-sheets and most obviously in the strato-cumulus which marks the condensation-limit in the eddying mass. By its own turbulent motion it cools its own upper levels and to the same extent warms its lower levels if the ground is not too cold; and forms fogs if it is so.

CHAPTER V

THE RELATION OF TEMPERATURE AND WEATHER TO BAROMETRIC PRESSURE

The simple regularity of relationship to pressure which has been shown to hold for the motion of air has no counterpart in the case of any other of the meteorological elements. In order to approach the subject at all we must begin by giving special names to the various parts of a complex distribution of pressure.

Following Abercromby, we may give a general description of the kind of weather that may be expected in the region where the isobars group themselves in the shapes known as cyclone, anticyclone, straight isobars, secondary depression, V-shaped depression, wedge-shaped isobars, or col. We can take account of many interesting facts characterised by the special titles of surge, level, and sequence of weather; we can formulate the results of prolonged study of weather maps by defining types of weather, or, more strictly, types of barometric distribution, draw conclusions as to their relationship, and hence, as to the sequence of types: but the statements will have to be, for the most part, of a general character and liable to exceptions which are sometimes very disappointing for the forecaster.

The absence of any rule of converse or reciprocity is perhaps the most striking feature about this part of our subject. When we were dealing with the relation of pressure and wind we could say with equal confidence, either, if you face the wind (in the northern hemisphere) the low pressure will be on your right, or if you face the centre of low pressure the wind will pass you from left to right, but we cannot do the same with regard to temperature, or cloud, or

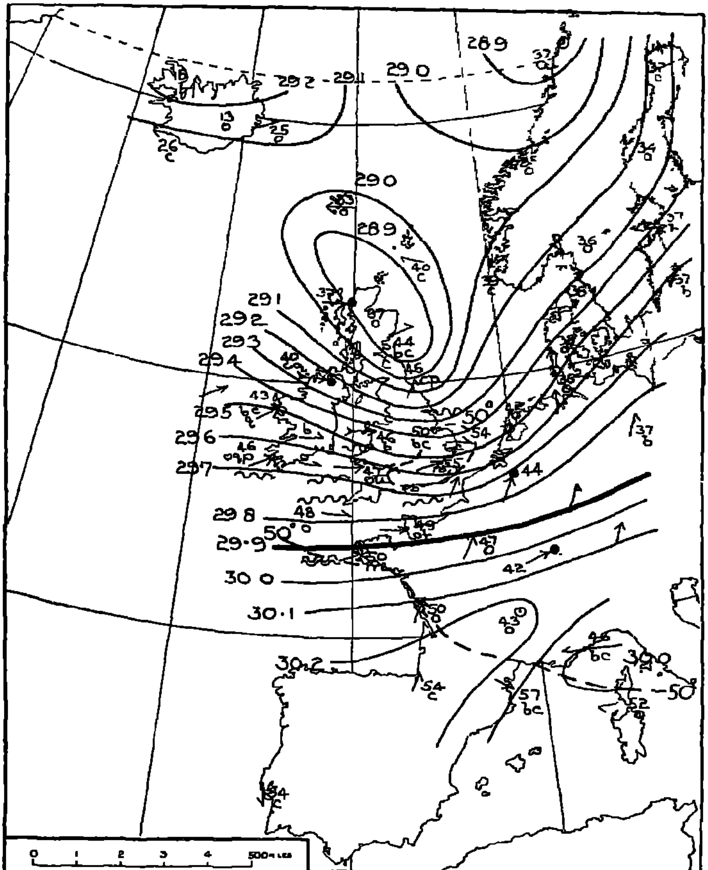
rain, or snow, or fog. It is generally true that in winter a cyclone is accompanied by warm weather in certain parts of its area, it is by no means true conversely that the occurrence of warm weather in winter means that the locality is in a particular region of a cyclone. It is more often true than not that the front central region of a cyclone is rainy. It is by no means so frequently true that when it is rainy the locality is in the front central region of a cyclone. When it is foggy on land the weather is anticyclonic, but when the weather is anticyclonic it is not necessarily foggy.

No doubt the reason for these important differences is that in the case of wind there is a mathematical or dynamical relation that may be called one of cause and effect between the wind and pressure distribution, and it is otherwise with the other elements. Rain is due to certain physical conditions which often exist in a cyclone but not exclusively there. Fog requires something in addition to a suitable distribution of pressure for its production. Thus the explanations which we are able to give of the association of temperature and other elements with pressure distribution are only partial and provisional. As soon as we can give a complete dynamical explanation of the phenomena our statements of relationship will become precise, and the converse statements will hold. For the present we must be content with the empirical results supplemented by such partial explanations on dynamical or physical grounds as we are able to give.

I propose first to take the association of the different elements with selected types of isobars as described by Abercromby.

In the preliminary consideration of the use of synoptic charts in Chapter III., we recognised two characteristic distributions of isobars to which the names of cyclone and anticyclone have been given. We have seen that an anticyclone covers a region of light airs, and, we may now add, generally fair weather, often with fog in winter on the land or in summer on the sea, whereas a cyclone is generally associated with strong

1907. March 18, 8 a.m.



CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
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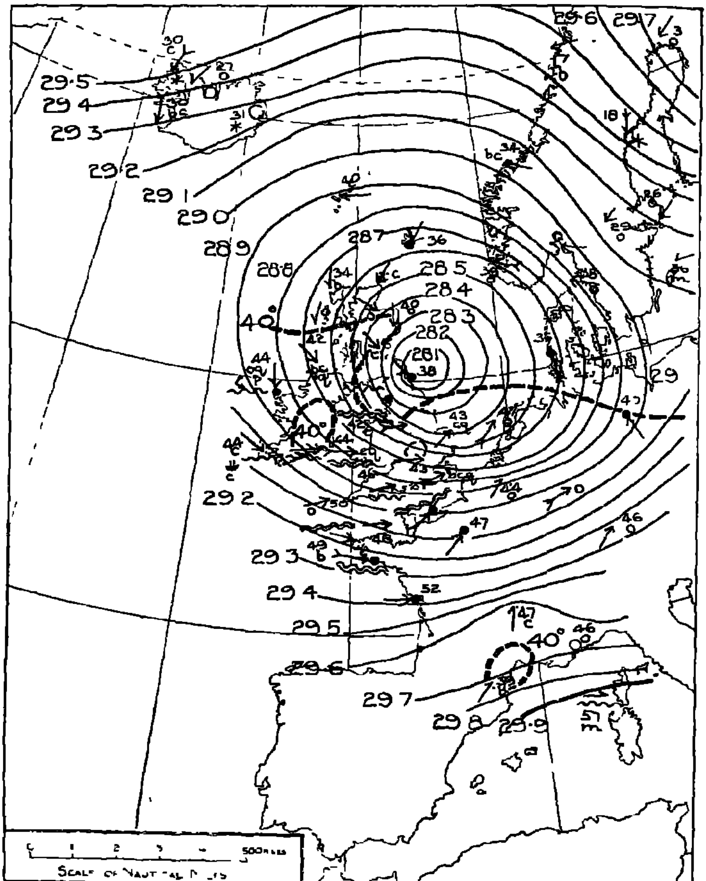
29·0	982·0	29·5	999·0	30·0	1015·9
29·1	985·4	29·6	1002·4	30·1	1019·3
29·2	988·8	29·7	1005·7	30·2	1022·7
29·3	992·2	29·8	1009·1		

Temperatures are given in figures ; the dotted line shows the isotherm of 50° F., 283 t.

FIG. 32.—Weather Chart of the Morning after the Wrecks of the *Jebba* and *Suevic* on the coasts of Cornwall and Devon.

1909. December 3, 7 a.m.



CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
28·1	951·6	28·8	975·3	29·5	999·0
28·2	954·9	28·9	978·6	29·6	1002·4
28·3	958·3	29·0	982·0	29·7	1005·7
28·4	961·7	29·1	985·4	29·8	1009·1
28·5	965·1	29·2	988·8	29·9	1012·5
28·6	968·5	29·3	992·2	30·0	1015·9
28·7	971·9	29·4	995·6		

Temperatures are given in figures ; the dotted line shows the isotherm of 40° F., 277·4 t.

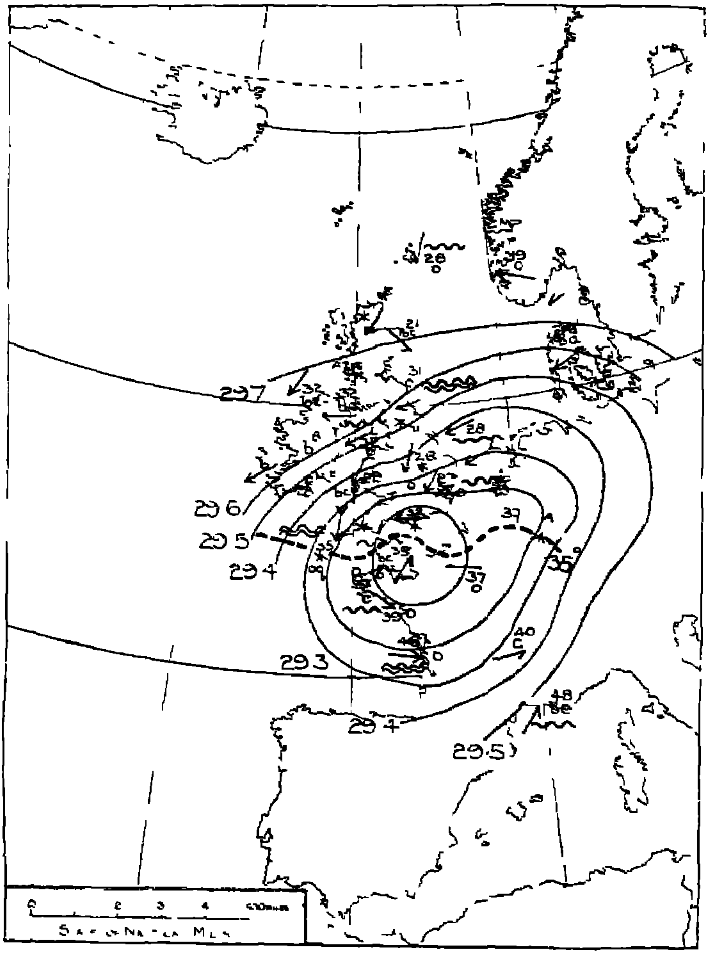
FIG. 33.—Chart for the Morning of the Wreck of the Manx Steamer, *Ellan Vannin*.

winds or gales, rainy or showery weather, rapid changes, and other characteristics of energetic action in marked contrast with the inertia and mild persistence of an anticyclone. Hence the cyclone figures much more largely in meteorological reminiscence than the anticyclone. It may be useful here to refer to some of the cyclonic disturbances which have become historic on account of the destruction for which they were responsible.

We have already seen Admiral FitzRoy's representation of the *Royal Charter* storm of 1859, and a representation of the depression which caused the wreck of the Great Eastern Railway Company's steamer *Berlin*, off the Hook of Holland, on February 20, 1907. With extracts from Abercromby's book later on we shall give his representation of the *Tay Bridge* storm of December 28, 1879. In this chapter (Fig. 32) we give the chart of meteorological conditions under which, in strong wind with fog, the Elder Dempster liner *Jebba* and the White Star liner *Sueric* both went ashore off the south coast of England in the night of March 17—18, 1907. Fig. 33 represents the pressure and winds of the notable gale of December 3, 1909, in which the Isle of Man steamer *Ellan Vannin* foundered with all hands off the mouth of the Mersey.

We add also charts for two notable snowstorms. Fig. 34 shows the sequel of the depression which caused the snowstorm of January 18, 1881. The restricted area covered by observations on January 19 is an unmistakable sign of the damage to telegraph wires caused by the snow. The storm was a memorable one because it disorganised the railway service and deprived London of its milk supply. Personally, I have reason to recollect it, not only because I had to spend three days on a journey by railway from London to Birmingham, but also because of the unique experience of seeing the platforms of the Metropolitan underground railway station at King's Cross an inch deep in snow, which had been carried about in fine crystals by a very strong and very cold easterly wind.

1881. January 19 8 a m.



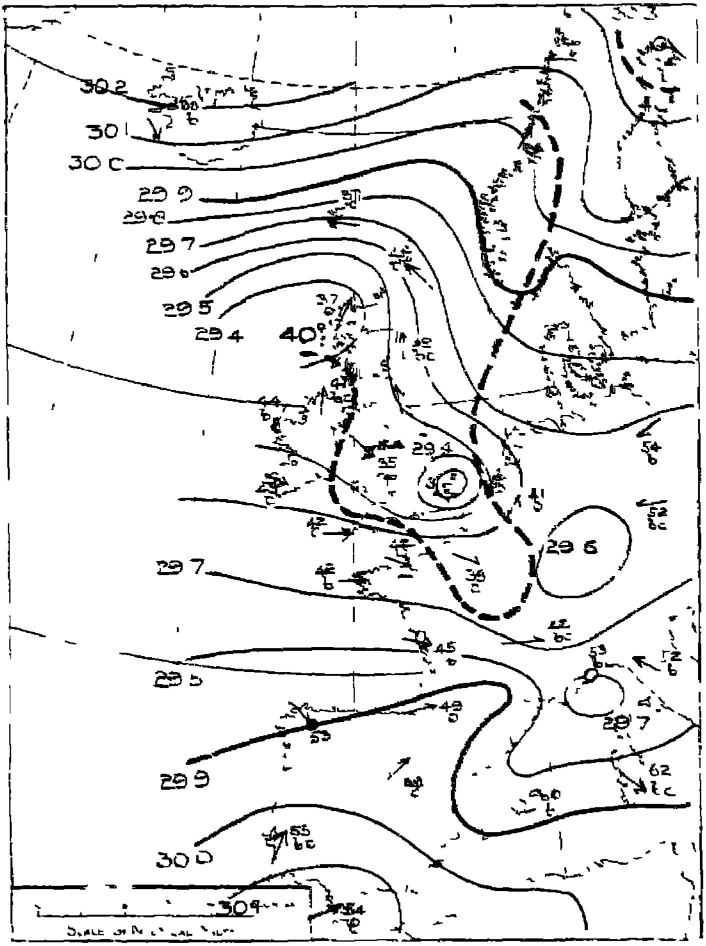
CONVERSION TABLE.

In	Mb	In.	Mb	In.	Mb
29 1	985 4	29 4	995 6	29·6	1002 4
29 2	988 8	29 5	999·0	29·7	1005 7
29 3	992 2				

The dotted line is the isotherm of 35° F., or 274 7 t.

FIG. 34.—Chart for the Morning following the great snowstorm of January 1881

1908. April 25, 6 p.m.



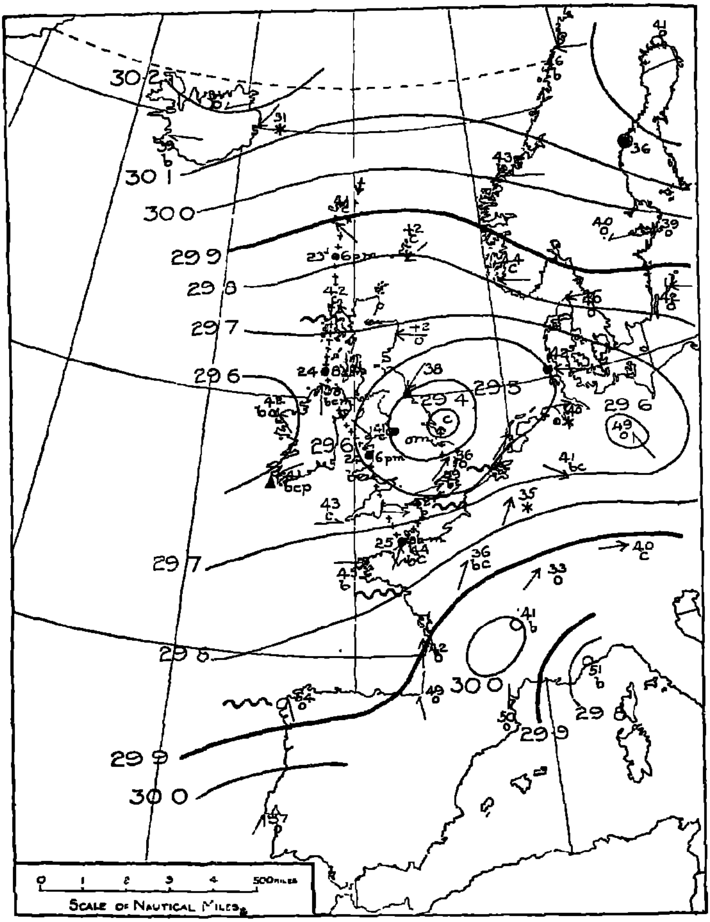
CONVERSION TABLE.

In.	Mb	In.	Mb	In.	Mb.
29·2	988·8	29·6	1002·4	30·0	1015·9
29·3	992·2	29·7	1005·7	30·1	1019·3
29·4	995·6	29·8	1009·1	30·2	1022·7
29·5	999·0	29·9	1012·5		

The dotted line is the isotherm for 40° F., 277·4 t.

FIG. 35A.—Snowstorm in Spring.

1908. April 26, 8 a.m.



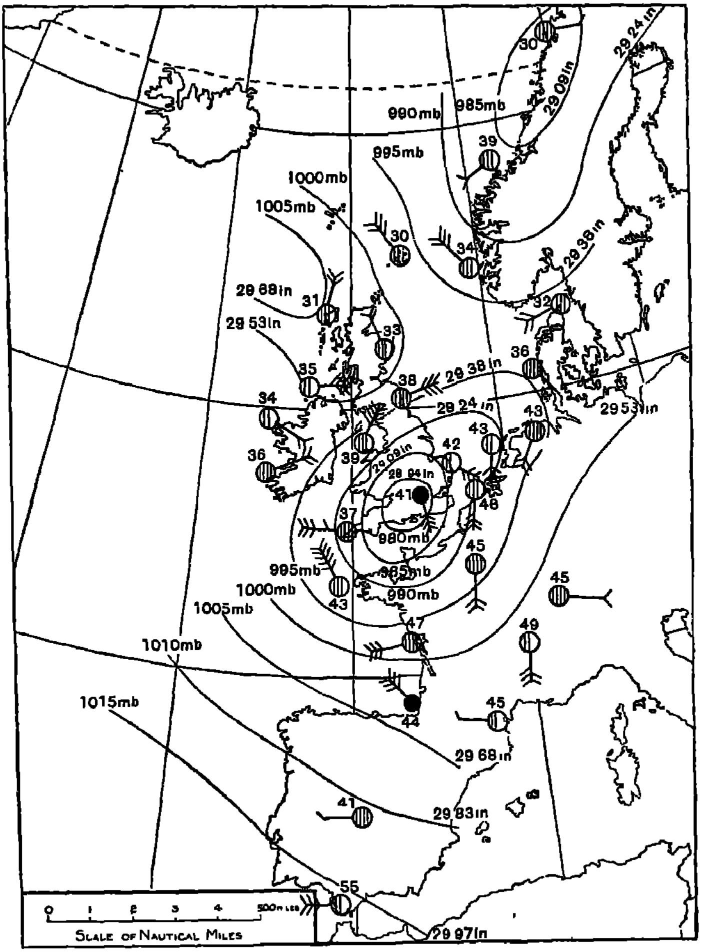
Conversion Table.

In.		Mb.	In.		Mb.	In.		Mb.
29·4	.	995·6	29·7	.	1005·7	30·0	.	1015·9
29·5	.	999·0	29·8	.	1009·1	30·1	.	1019·3
29·6	.	1002·4	29·9	.	1012·5	30·2	.	1022·7

The path of the centre of the depression is shown by a line of crosses with figures against its positions on the 23rd (6 p.m.), 24th (8 a.m. and 6 p.m.), and the 25th (8 a.m.); the position at 6 p.m. on the 25th is shown by the preceding figure.

Fig. 35b.—Snowstorm in Spring (*continued*).

1916. March 28, 7 · .m.

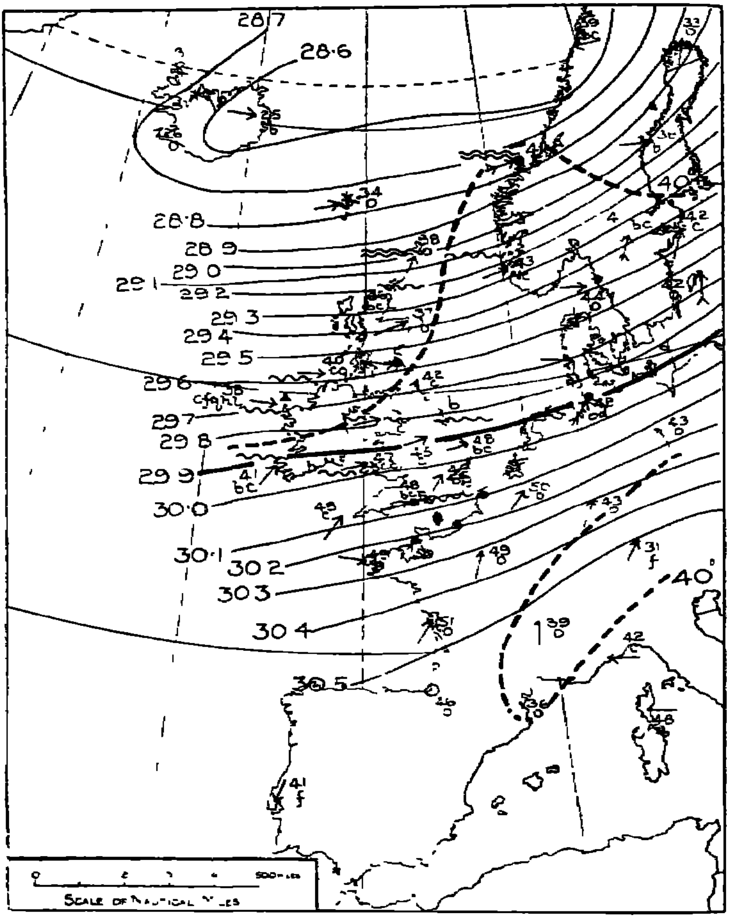


Temperatures on the Fahrenheit Scale are given in degrees. The isotherm of 40° F., 277·4 t, separates the warmer part of the cyclone from the colder.

The map should be compared with that of the great snowstorm of 1881 (Fig. 34).

FIG. 36.—Snowstorm in the Spring of 1916.

1910. January 10, 7 a.m.



Conversion Table.

In.	Mb.	In.	Mb.	In.	Mb.
28·6	968·5	29·3	992·2	30·0	1015·9
28·7	971·9	29·4	995·6	30·1	1019·3
28·8	975·3	29·5	999·0	30·2	1022·7
28·9	978·6	29·6	1002·4	30·3	1026·1
29·0	982·0	29·7	1005·7	30·4	1029·4
29·1	985·4	29·8	1009·1	30·5	1032·8
29·2	988·8	29·9	1012·5		

The dotted line is the isotherm for 40° F., 277·4 t.

Fig. 37.—Straight Isobars.

Another example of a depression referred to for its historic interest is represented in Figs. 35A and 35B. It was the occasion of great snowstorms occurring after Easter on April 24 to April 26, 1908. Again my personal recollection aids my meteorological memory, because in the failing daylight, about 7.30 p.m. on the evening of April 25, I found myself in the setting of a winter landscape appropriate to a December afternoon held up by snow for three-quarters of an hour in a London express on the North-Western main line between Stafford and Rugby, and doubtful whether the train would reach it destination.

To these we now add a chart for March 28, 1916 (Fig. 36) which represents a deep depression which gave from 5 to 10 inches of snow over the Midland Counties of England and gusts of wind approaching hurricane force at Benson (near Oxford), Kew Observatory, Spurn Head and Yarmouth.

CLASSIFICATION OF THE FORMS OF ISOBARS

The examples cited will be sufficient as illustrations of the grouping of isobars known as *cyclones* or *cyclonic depressions*. We have already considered examples of *anticyclones* in Chapter III. (Figs. 16, 17), and we shall revert to their consideration in a subsequent chapter. We now proceed to the illustration of other groups of isobars according to the classification used by Abercromby and, indeed, by meteorologists generally. The illustrations are taken from the Daily Weather Report of the Meteorological Office.

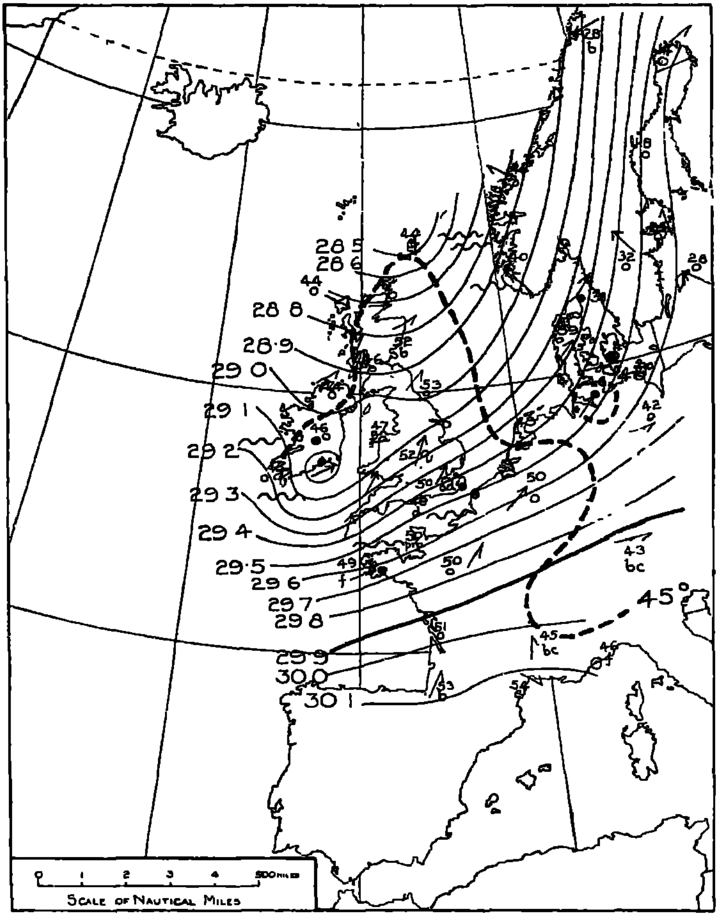
Fig. 37, for January 10, 1910, gives us an example of *straight isobars*. It is evident that they represent really the intermediate region between a cyclone and an anticyclone both of vast area. The whole region is practically the theatre of action of a vast westerly current with an almost uniform gradient extending altogether over two inches of mercury between the Mediterranean and Iceland. The reader should notice the variability of the weather in this great river of air which seems, at first sight, to be so uniform. The letters

indicate the state of the sky at the several stations, the black dots show where it is raining, and a black triangle denotes hail. An inspection will show that blue sky, detached clouds, overcast sky, rain, drizzling rain, snow, passing showers, hail, lightning, and fog are all to be found in different parts of what seem to be on paper perfectly similar meteorological conditions. It is indeed fair to remark that the varieties of weather under straight isobars are among the most interesting and at the same time most perplexing subjects of meteorological study. In passing, I should like to call attention to the difference of temperature in different parts of this great current, and for this purpose I have had clearly marked the isotherm of 40°, which separates what may be called the warm part of the current from the cold part. Notice that the cold has encroached from the northward in the west, because we shall draw attention to similar encroachments in Chapter XI.

The next item in the classification is the secondary depression. This is the name given to any distortion of the symmetry of the isobars which may be represented merely by a sinuosity, or sensible deviation from the symmetrical run of the isobar with corresponding alterations in the direction and strength of the wind. or it may be exaggerated until a secondary centre of low pressure with its own wind circulation is shown. In either form the secondary is a very difficult subject for the forecaster, because we have as yet no general explanation of its occurrence and its influence upon the weather. Even when it is only shown as slight sinuosities of the isobars its influence is very marked. As regards the wind, it is clear that for a deviation to the southward in the isobars of a depression centred in the far north, we have an exaggeration of wind in one part and reduction of it in another; and, as regards the weather, the passage of a secondary is often attended by rain squalls, or even thunderstorms.

Recently, in examining the results of observations of pilot balloons, I have been struck with the occasional occurrence of an upper wind of great vertical thickness from a northerly

1895. March 24, 8 a.m.



CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
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28·6	968·5	29·2	988·8	29·8	1009·1
28·7	971·9	29·3	992·2	29·9	1012·5
28·8	975·3	29·4	995·6	30·0	1015·9
28·9	978·6	29·5	999·0	30·1	1019·3
29·0	982·0	29·6	1002·4		

The dotted line is the isotherm for 45° F., 280·2 t.

FIG. 38.—Small Secondary Depression, with Centre over the South-East of Ireland, giving rise to very strong Gales.

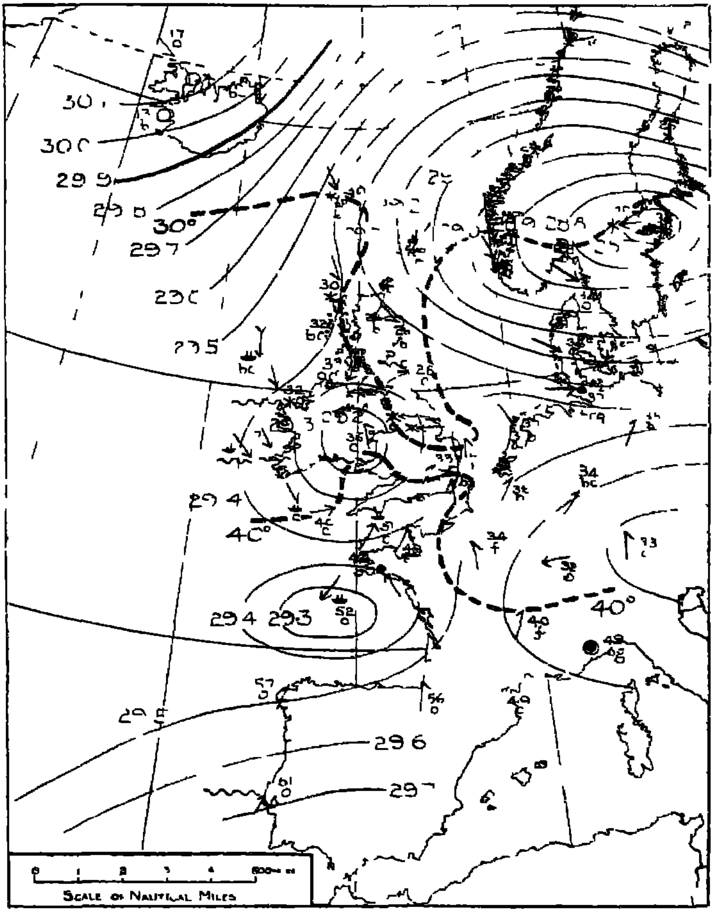
or north-westerly point above a surface wind from the south or south-west. They were almost invariably followed by the appearance of a secondary depression. At the time these upper winds were regarded as the outflow from above a central region of low pressure over the Iceland seas. But Buys Ballot's law points to them as evidence of a centre of low pressure in the upper air to the north-eastward and perhaps to the shift of the axis of the upper part of a low-pressure system through some few hundred kilometres in that direction. A secondary might also be the consequence of such a displacement after the manner indicated in Chapter X., p. 313.

The first illustration of a secondary depression, that for March 21, 1895 (Fig. 38), is one which shows a detached centre. It will recall to many Cambridge men a Sunday afternoon when, without any rainfall at all, hundreds of trees were blown down in a brief space of time between 2 o'clock and 4 o'clock, and many of the streets were rendered impassable by fallen timber. The havoc wrought by the slight accentuation of the isobars on the southern side of the secondary centre extended from South Wales to Norfolk, and the remains of it are still visible in many places. The wind in some cases cut a clean path, recalling the tornados of the United States. The map shows rain in the immediate neighbourhood of the centre of the secondary at 8 a.m., but apparently rainfall was not necessary to maintain the energy of the disturbance, for none fell in Cambridge during its passage.[1] The temperature distribution in this case also is very remarkable, as shown by the area enclosed by the isotherm of 45°.

The transitional stage between the mere sinuosity in the isobar and the detached and almost independent centre of a satellite depression, is aptly called the V-shaped depression, because a series of isobars have that shape and it is easily recognisable. Almost any succession of weather charts would furnish illustrations of the various forms of secondary

[1] Further information about this secondary is given in "Proc. Roy. Soc.," vol. 94A, pp. 34—52. 1917.

1909. December 19, 7 a.m.



CONVERSION TABLE

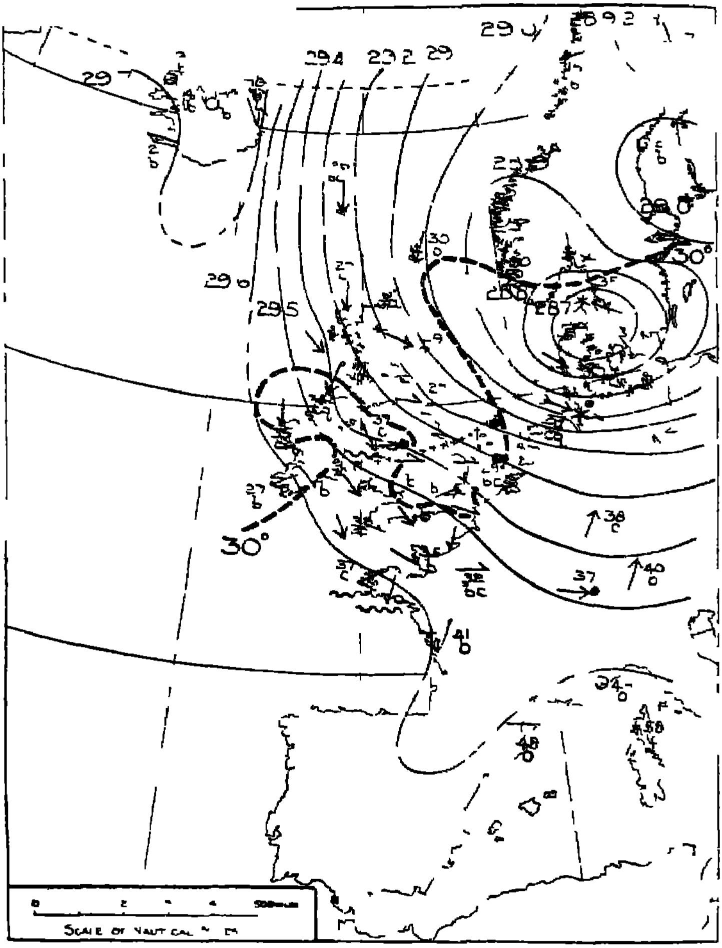
In	Mb	In	Mb	In	Mb
28.7	971.9	29.2	988.8	29.7	1005.7
28.8	975.3	29.3	992.2	29.8	1009.1
28.9	978.6	29.4	995.6	29.9	1012.5
29.0	982.0	29.5	999.0	30.0	1015.9
29.1	985.4	29.6	1002.4	30.1	1019.3

The isotherms are for 30° F., 271.9 t., and 40° F., 277.4 t.

FIG. 39.—Secondaries.

Figs. 39 to 44 form a series of Charts showing a succession of secondary depressions, V-shaped depressions and sinuosities in the isobars in the period December 19—24, 1909.

1909 December 20 7 a m



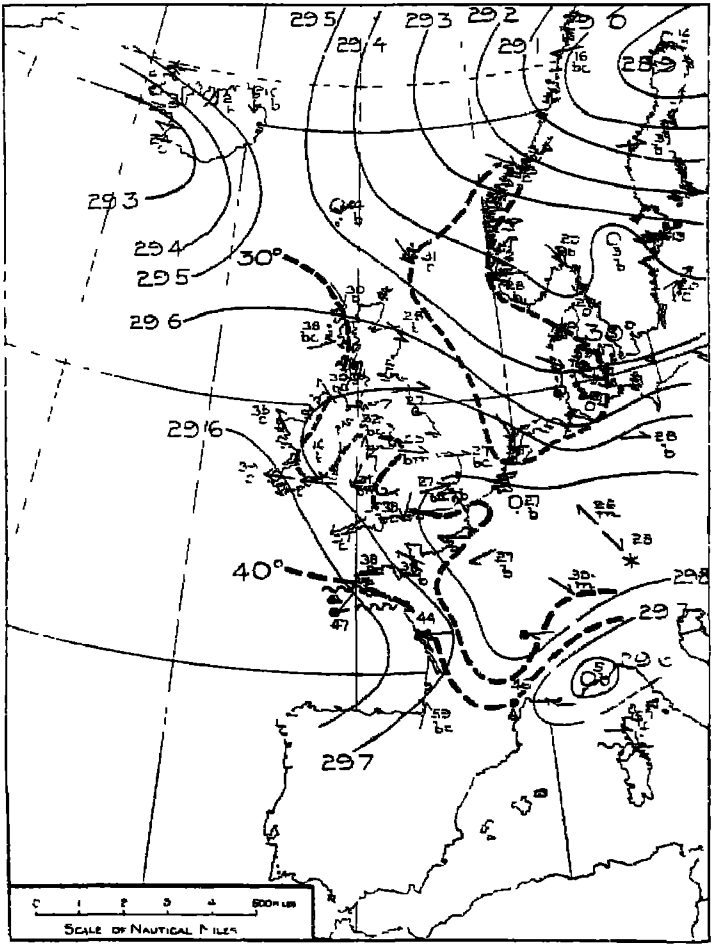
CONVERSION TABLE

In	Mb	In	Mb	In	Mb
28 8	975 3	29 2	988 8	29 5	999 0
28 9	978 6	29 3	992 2	29 6	1002 4
29 0	982 0	29 4	995 6	29 7	1005 7
29 1	985 4				

The dotted line is the isotherm of 30° F 271° t
The line of crosses marks the path of the centre

FIG 40 —Sinuosities in Isobars

1909. December 21, 7 a.m.



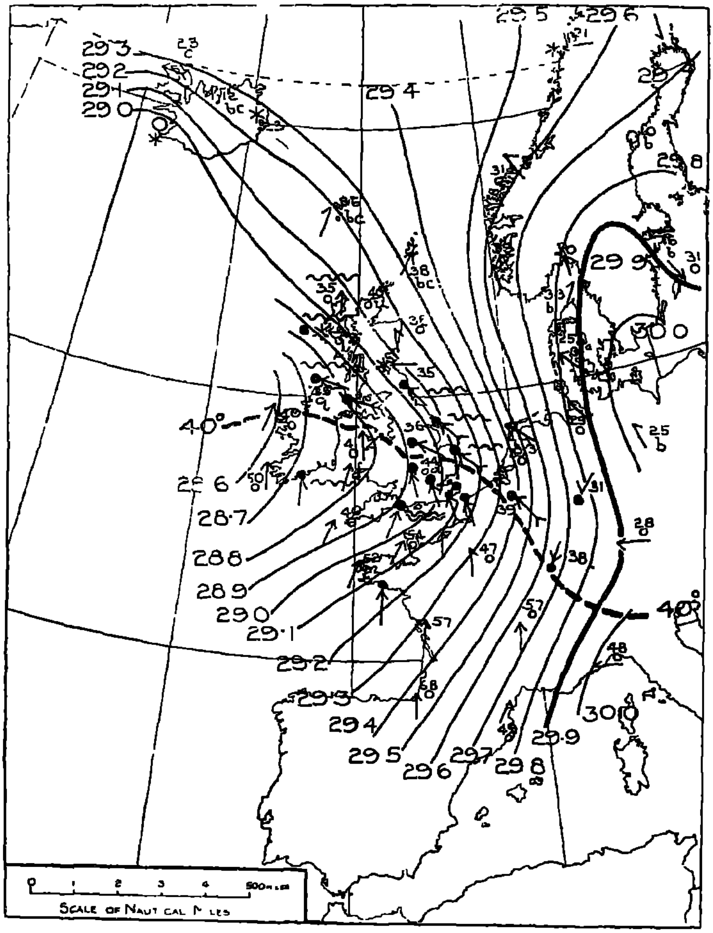
CONVERSION TABLE.

In	Mb	In	Mb	In.	Mb.
28·9	978·6	29·3	992·2	29·6	1002·4
29·0	982·0	29·4	995·6	29·7	1005·7
29·1	985·4	29·5	999·0	29·8	1009·1
29·2	988·8				

The isotherms are for 30° F., 271·9 t, and 40° F., 277·4 t.

FIG. 41.—Complex System of Depressions.

1909. December 22, 7 a.m.

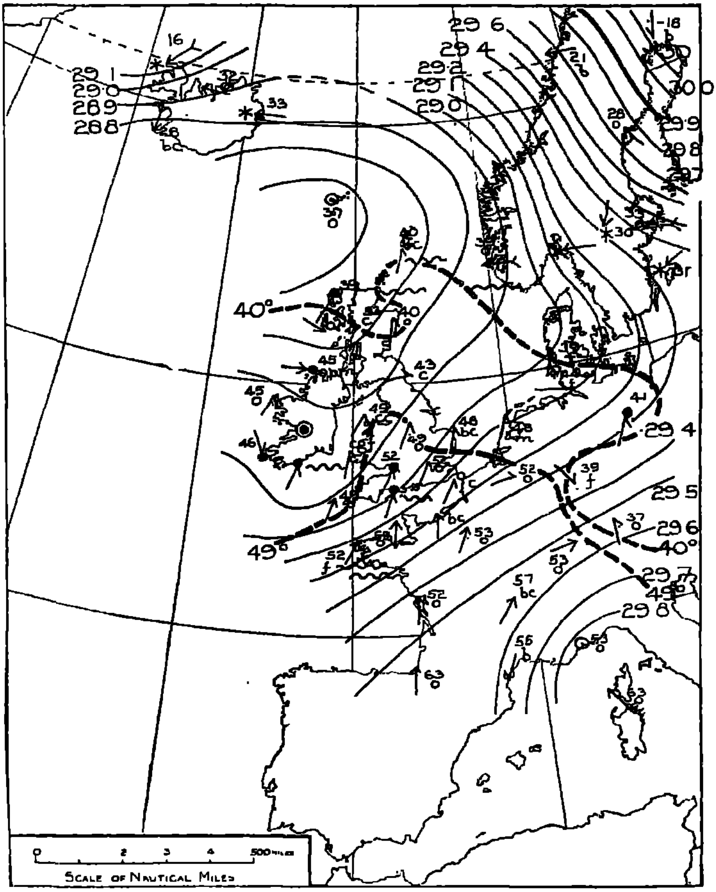


Conversion Table.

In.	Mb.	In.	Mb.	In.	Mb.
28·6	968·5	29·1	985·4	29·6	1002·4
28·7	971·9	29·2	988·8	29·7	1005 7
28·8	975·3	29·3	992·2	29·8	1009·1
28 9	978·6	29·4	995·6	29·9	1012·5
29·0	982·0	29·5	999·0	30·0	1015·9

Fig. 42.—V-shaped Depression with its Axis nearly along the Isotherm of 40° F., 277·4 t.

1909. December 23, 7 a.m.



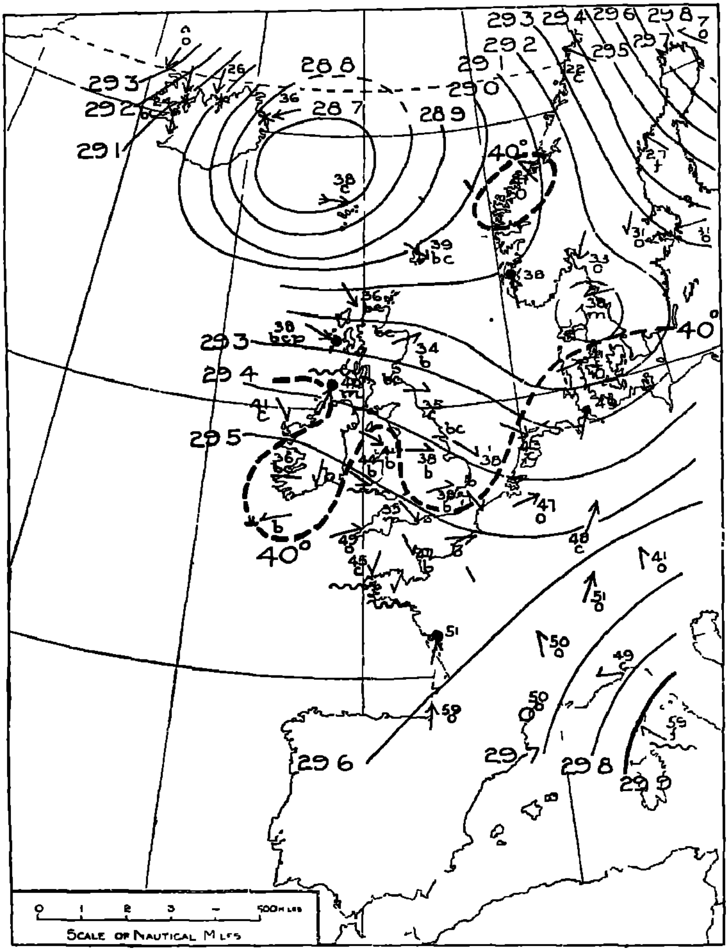
CONVERSION TABLE.

In.	Mb	In.	Mb.	In.	Mb.
28·6	968·5	29·2	988·8	29·7	1005·7
28·7	971·9	29·3	992·2	29·8	1009·1
28·8	975·3	29·4	995·6	29·9	1012·5
28·9	978·6	29·5	999·0	30·0	1015·9
29·0	982·0	29·6	1002·4	30·1	1019·3
29·1	985·4				

The isotherms are for 40° F., 277·4 t., and 49° F., 282·4 t.

FIG. 43.—V-shaped Depression already shown in Fig. 42, followed by another with its Axis nearly North and South.

1909. *December 24, 7 a m.*



CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
28·7	971·9	29·2	988·8	29·6	1002·4
28·8	975·3	29·3	992·2	29·7	1005·7
28·9	978·6	29·4	995·6	29·8	1009·1
29·0	982·0	29·5	999·0	29·9	1012·5
29·1	985·4				

The isotherms are for 40° F., 277·4 t.

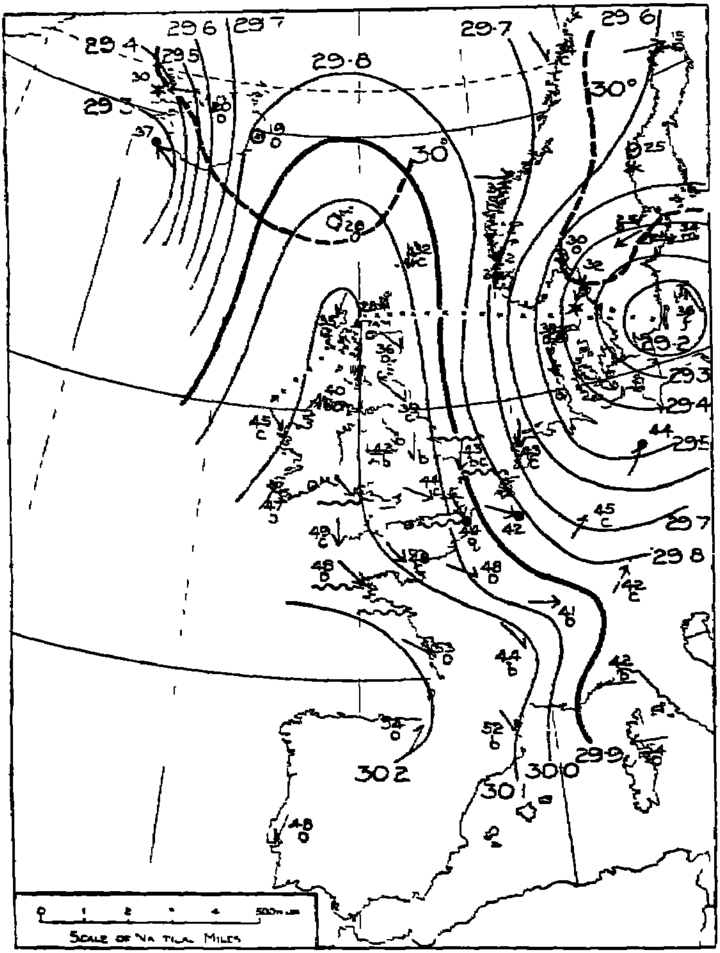
FIG. 44.—Secondary Depression.

depression. I have taken the series from December 19 to December 24, 1909, because that period was marked by secondary depressions of every variety.

Fig. 39, for December 19, shows what may be called a primary depression over the Gulf of Bothnia and two detached secondary or satellite depressions, one over the British Isles and the other over the Bay of Biscay. The snow on the north-eastern side of the former is noteworthy. The chart for December 20 (Fig. 40) shows the secondary almost merged in the primary, but there are a number of sinuosities, one of them giving rain at Liverpool. December 21 (Fig. 41) shows a new depression coming on which proved to be of great depth and which developed a V-shaped modification on its east side by December 22 (Fig. 42). The V shows very clearly the invasion of the region of easterly wind by a southerly wind with a marked difference of temperature, and rain or snow over the junction. The 40° isotherm, which has been drawn on the chart, marks the separation of the warm and cold currents. This particular example of the V is interesting to those who experienced the changes of the night of December 21. I was in Birmingham on that occasion. The evening was bitterly cold with a penetrating east wind. At 10 o'clock it began to snow, and much snow fell between 10 o'clock and midnight; shortly after midnight the southerly wind displaced the easterly at the surface, and rain with a sudden thaw supervened. By morning the snow had disappeared. Such sudden changes are characteristic of V-shaped depressions.

On December 23 (Fig. 43) the remains of the V-shaped depression are shown over Denmark, but another is shown on the same chart over Ireland. Notice that the changes of temperature in the two V's are of opposite character. The axis of the new V is running from north to south instead of from nearly west to east as in the old, and we note a cold wind displacing a warm one as the trough of the V passes. The isotherms for 40° and 49°, which are shown on the chart, illustrate these curious temperature relations.

1909. December 29, 7 a.m.



Conversion Table

In.	Mb.	In.	Mb.	In.	Mb.
29·2	988·8	29·6	1002·4	30 0	1015 9
29·3	992·2	29·7	1005 7	30·1	1019 3
29·4	995 6	29·8	1009 1	30 2	1022 7
29·5	999·0	29·9	1012 5		

The line of crosses marks the path of the centre of the depression
Temperatures are given in Fahrenheit degrees.

Fig 45.—Wedge-shaped Isobars

By 7 a.m., December 24 (Fig. 44), the last of the series, the weather has become fine over England, the original V has become a detached secondary over Sweden, and the second V is, if anywhere, over the Bay of Biscay.

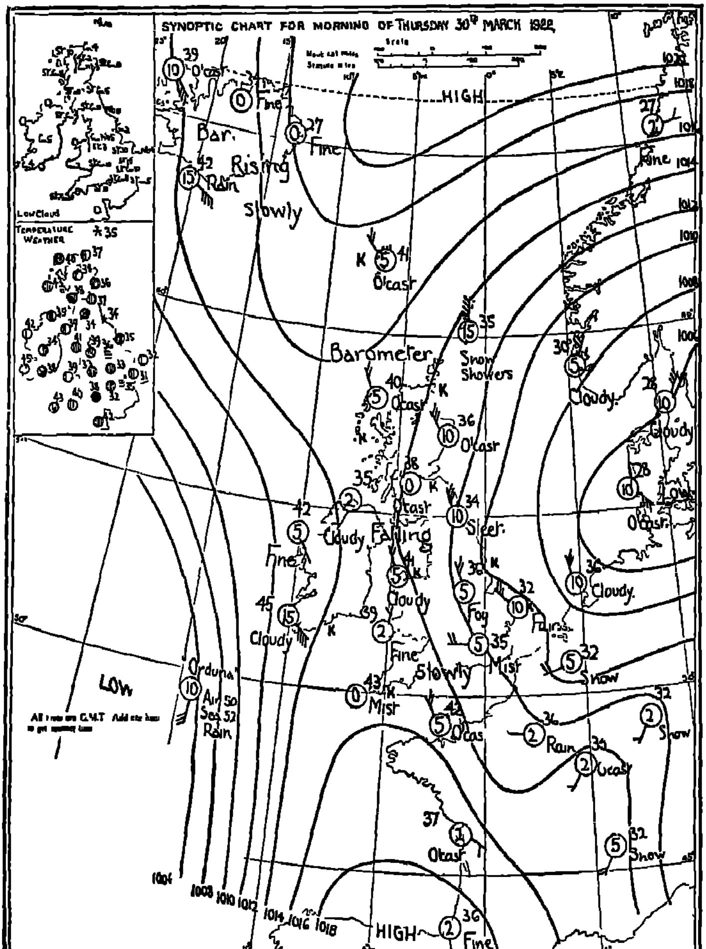
Fig. 45 represents the chart for December 29, 1909, and is reproduced as a good specimen of a *wedge*, the northern extension of an anticyclone thrust between two lows, very much the inverse of a V-shaped depression as regards winds, but quite different from it in meteorological character. It is often the occasion of most brilliant weather.

Fig. 46 represents what is known as a *col*, the saddle-shaped region between two lows and two highs. Its weather is of a very dubious character. In the summer it is often a region of thunderstorms. on this particular occasion it seems to have been a region of overcast sky and fog.

The last of the charts to represent Abercromby's classification of isobars are those for July 20 and 21, 1909 (Figs. 47A and 47B) which are selected to show what he calls "surge"—that is to say, a general alteration of pressure that seems to be superposed upon the changes related to a low-pressure centre. The change will be best followed in this case by noting the position of the 29·9 isobar and the readings for the middle region of the anticyclone to the south. Notice that in the interval between the two maps the middle region of a depression has moved from the south-west of Iceland to the Faroe, and the depression has deepened. The 29·9 line has bulged and travelled to the southward, while the anticyclone has lost ·2 inch from its intensity without much change of shape. Thus, it would appear that in consequence of some general atmospheric change, pressure has diminished by one-fifth of an inch over nearly the whole map, while the Icelandic depression has moved eastward and spread southward independently of the general change.

The types of isobars which have been represented in this chapter are all associated with the characteristics and behaviour of cyclones and only incidentally afford material for the study of

1922. March 30, 7 h.



For another example see 1911, May 27, 7 a.m., which was preceded by rainfall of 2·016 inches at Great Billing Rectory, Northampton, and of 1·44 at Belvoir Castle, on the north side of southern low of col.

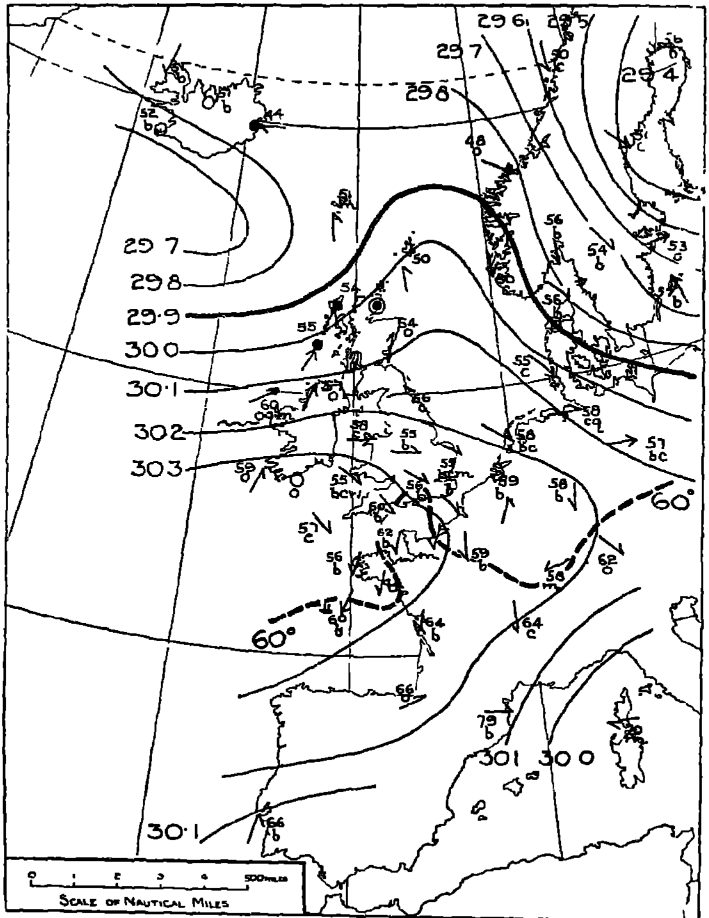
Fig. 46.—Col.

the relation of a cyclonic depression to its environment. The peculiar character of the weather of the British Isles in the year 1921, when the rainfall of a large part of England, especially of the South-Eastern and Eastern districts was about half the normal allowance, has naturally led to a close scrutiny of the daily maps in the endeavour to detect the causes of the prolonged drought. The most general conclusion to be gathered from the scrutiny is that there was established from time to time over the southern part of the kingdom, with much more than the usual frequency, especially in the summer months, a ridge of high pressure, connecting the permanent anticyclone of the Atlantic Ocean with a north polar anticyclone indicated in the map of the normal distribution of pressure, between the great cyclonic circulation of the summer monsoon of Asia and the cyclonic circulation centred, on the average, near Greenland. These two great circulations gave, on the one side, a north-easterly or easterly current from Siberia towards the permanent North-East Trade off the coast of Africa and, on the other side, the great stream of air from the west across the North Atlantic turning to the north-east along the Norwegian coast. From time to time between these two great currents lay the ridge of high pressure which fluctuated in intensity and in position; and whenever it was established gave a corridor of ridge-weather over the British Isles with typical fine-weather conditions.

Such conditions are not unusual south of the English Channel. but, in the year 1921, the ridge of high pressure and the corresponding fine weather were further north than usual. The corridor is always liable to be invaded and interrupted by cyclonic depressions of the Atlantic, mostly centred on a line to the north of us; but not infrequently in ordinary years the centres of the depressions pass up the Channel or across Ireland and England, In 1921 many approached and threatened the rain that was much needed, but they were apparently restrained from doing more than produce cloudy skies without rain.

Some of the maps gave a definite impression of the movement of a vigorous cyclone being barred by a broad current of air from

1909. July 20, 7 a.m.



CONVERSION TABLE.

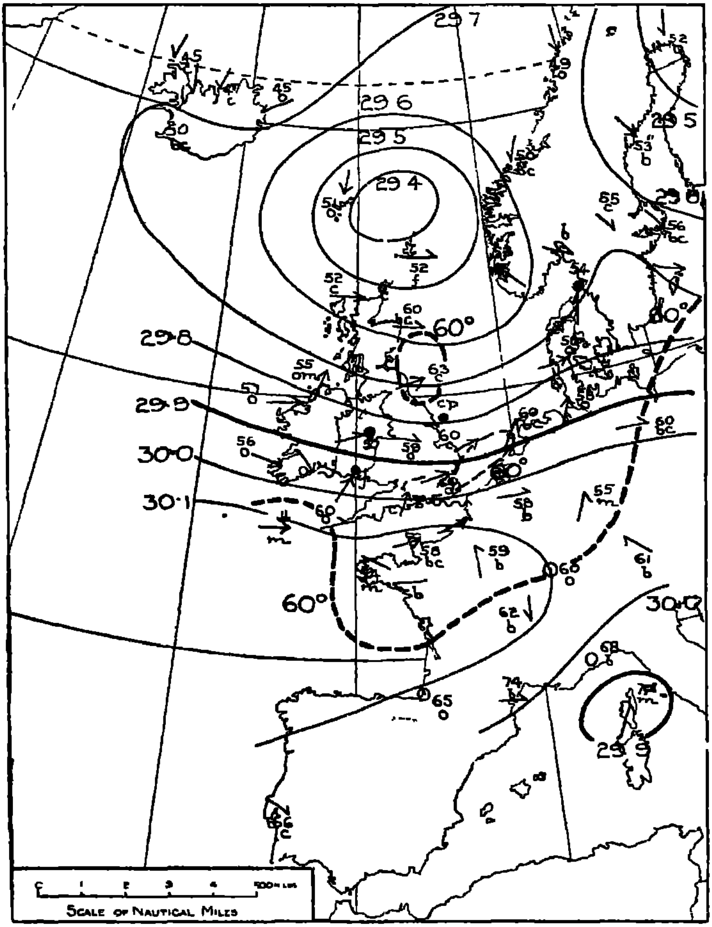
In.	Mb.	In.	Mb.	In.	Mb.
29·4	995·6	29·8	1009·1	30·1	1019·3
29·5	999·0	29·9	1012·5	30·2	1022·7
29·6	1002·4	30·0	1015·9	30·3	1026·1
29·7	1005·7				

The isotherm is for 60° F., 288·6 t.

FIG. 47A.—Surge.

Figs. 47A and 47B show general "surge" of low pressure from the north superposed upon the details of pressure-distribution.

1909. July 21, 7 a.m.



Conversion Table.

In.	Mb.	In.	Mb.	In.	Mb.
29·4	995·6	29·7	1005·7	30·0	1015·9
29·5	999·0	29·8	1009·1	30·1	1019·3
29·6	1002·4	29·9	1012·5		

The isotherm is for 60° F., 288·6 t.

Fig. 47b.—Surge.

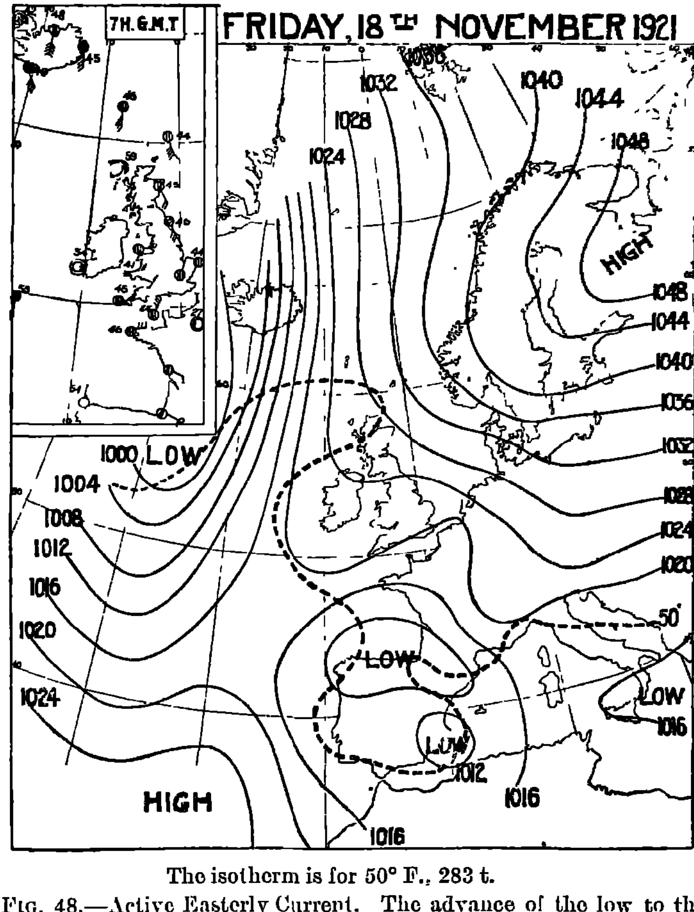
Figs. 47a and 47b show general "surge" of low pressure from the north superposed upon the details of pressure-distribution.

the east. It is perhaps desirable to recognise such a distribution as a type of isobars worthy of a place in our collection. We offer two examples (Figs. 48 and 49). The first presenting the map for 7 a.m. on Friday, November 18, shows a well-marked "low" over the Atlantic and a vast stream of air extending from the Gulf of Finland to the Mediterranean flowing against the isobars of the Atlantic "low," dividing and spreading northward and southward, forming a "low" over the Bay of Biscay on the one side and exaggerating the "high" over Finland on the other. The second, presenting the map for 18 h. of Saturday, November 12, shows very similar conditions, though the Atlantic "low" is more vigorous and the easterly stream less so. The latter shows very clearly by the dotted line of 1,022 mb. an anticyclonic ridge between the easterly and westerly air connecting with another high pressure east of the line of the Norwegian mountain range.

The ridge may fairly be said to be guided by the coastline of Europe from the high pressure of the Atlantic to that of the North Polar regions if we can regard the massif of Norway, for meteorological purposes, as an outlying island beyond the main coastline of the Continent.

How far the apparent influence of the easterly air impinging upon the Atlantic "low" represents a real dynamical effect we cannot say; the maps are very suggestive of the well-known experiment of a spinning ball supported by a jet of water. Even if that suggestion is too grotesque for serious consideration, the grouping of the isobars is instructive and does not come within any group already recognised in this chapter, nor does it appear as belonging to any one of the twenty-eight types in the classification by Lt.-Col. Gold described on p. 173. It is, however, probable that its absence is due to the limited area represented. Type VIIc. of that classification would probably show the structure which we have described if the lines were carried out further to the west. We should probably find it in many of our maps if we had details over land and sea to the south of us.

Mill-wheel isobars.



The isotherm is for 50° F., 283 t.

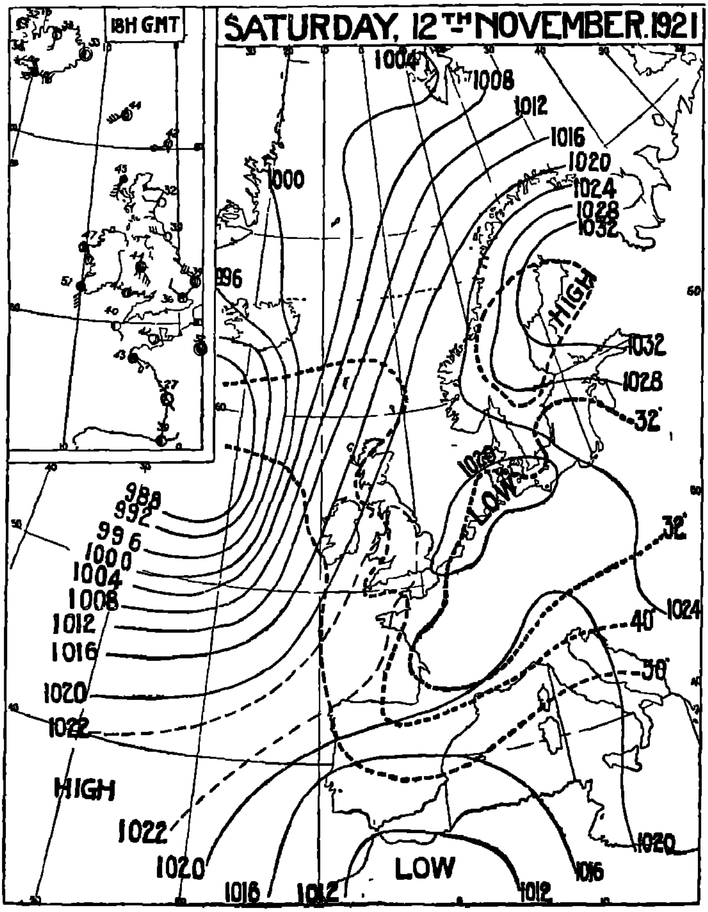
FIG. 48.—Active Easterly Current. The advance of the low to the south-west of Iceland appears to be resisted by the easterly current between the White Sea and the Mediterranean.

Note the col of high-pressure between the south-westerly current and the north-easterly current off N.W. Spain.

The lows in the south are suggestive of eddies in the diverted stream

A map of this type for 7 h., July 9, 1923, in which the current from the east was very warm, while that from the Atlantic was cool, is notable as the precursor of a thunderstorm in London in the night of July 9-10, said to be the most impressive within living memory. It occurred in the course of a spell of hot weather quite typical of isobars for east winds at that time of year.

Mill-wheel isobars.



Isotherm 32° F., 273 t.

FIG. 49.—Broad Easterly Current of Wind flowing between Finland and Northern Africa impinging upon the Eastern Margin of a Cyclone on the Atlantic.

Note the tongue of high pressure (1.022 millibars) over south-west England between the easterly and westerly current; also the spread of cold air from the east, and, in the inset chart, the discontinuity of wind between Faröe and Iceland.

THE PARTS OF CYCLONIC DEPRESSIONS

Not only do we require this classification of the forms of isobars, but we must be able to distinguish between different parts of the several units. The different portions of a cyclonic area present different general characteristics. The front and the rear of a V-shaped depression present almost opposite

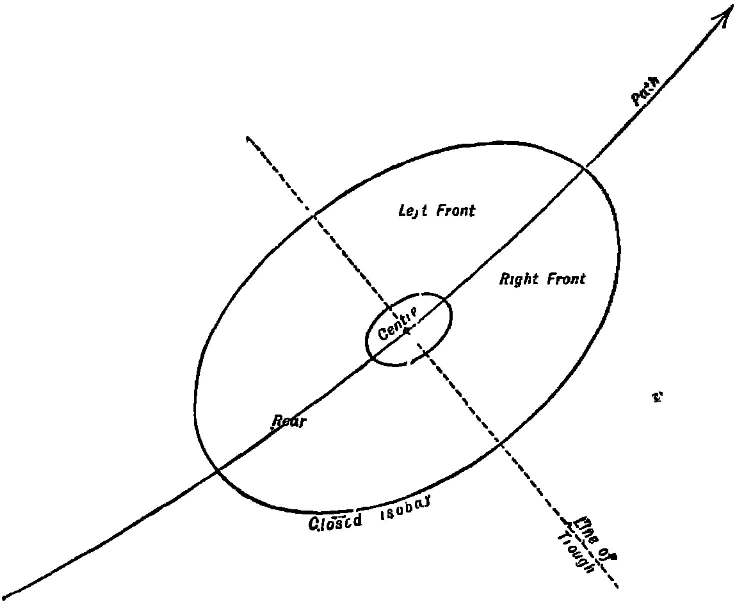


FIG. 50.—Nomenclature for Parts of a fully developed Cyclone.

characteristics. As a rule, the barometric distribution travels over a stretch of country with comparatively little change of form, and the path of the centre or minimum is a line of great importance, sometimes straight, generally curved. to which the characteristics of the different parts are referred. A line drawn through the minimum at right angles to the path is called the line of the "trough." It corresponds with the occurrence of the lowest barometric pressure at all stations affected by the depression, whether they are in the direct line of advance of

the minimum or not. The part of the depression on the advance side of the trough is called the front, the remaining part the rear. The front quadrant of the depression between the line of the path and the trough line on the right-hand side of the path of the depression as it advances, is called the right front. The corresponding quadrant on the other side of the path is the left front. This assignment of names to the different parts of a cyclonic area is represented in Fig. 70.

CHARTS FOR EXTENDED REGIONS

When we are dealing with a limited area like that of the British Isles, any one of the special groups of isobars above mentioned may be regarded as controlling our weather. The gradual extension of area either for the preparation of charts from day to day or for the special purposes of study as in the example of the Atlantic charts for the 13 months, August 1882 to August, 1883, enables us to regard these groups of isobars as forming parts of a complex pressure distribution. Figs. 61-63 of Chapter VI., show reproductions of three of the Atlantic charts, and upon them we can find illustrations of every typical group of isobars. If we watch the transformations taking place over the area as represented on successive maps, we shall find it difficult to retain the idea of a separate existence of these special types of isobars in the manner suggested by a study of the maps for more limited regions. It is, however, in many ways convenient to keep that classification in our minds, and we shall therefore deal with the relation of temperature and weather to the selected groups of isobars. When we have got the general ideas of association expressed, we will ask the reader to go into further and more precise detail as a step in the direction of tracing the physical explanation which underlies the phenomena.

TEMPERATURE

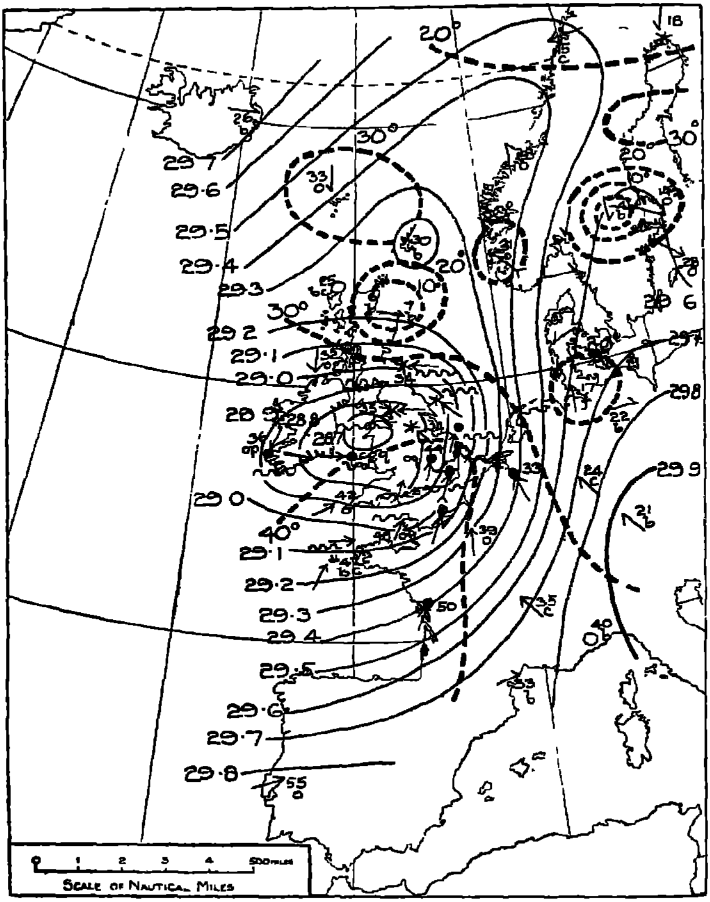
As regards temperature I cannot do better than refer to the examples in Chapter IV., and call attention here to the

chart for January 28, 1910 (Fig. 51). In this case the isotherms, or lines of equal temperature, which are drawn on a separate chart of the Daily Weather Report, are superposed as in previous figures upon the pressure map. The result is very striking. The area of warmth on the south and west of the isotherm of 40° includes the southern side and the right front of the cyclonic depression which is the conspicuous feature of the distribution of pressure. It practically covers all the winds between south and south-west. These winds are warm. There is a noteworthy demarcation between them and the south-easterly to southerly winds coming from France and Central Europe which are cold. There is a sharp fall of temperature between the southern and northern parts of the depression; the transition is quite abrupt and amounts to about 10° F. The coldness extends to the isobar of 29·2, which crosses the north of Scotland near Inverness. Further north a secondary depression is shown, and between the secondary centre and the primary is a centre of light airs and intense cold, as low as 10° F. It is cold, about 20° F., over east-central Europe where there is relatively high pressure, and another locality of intense cold, below zero Fahrenheit, is to be found over Sweden in a northern extension of the continental high pressure which forms a wedge there.

This distribution of temperature is quite typical of winter conditions, and it illustrates the great difficulty that there is in dealing with considerations of temperature. Notice particularly the want of symmetry as regards the distribution of temperature in the cyclonic area. Instead of being related to a centre like the pressure or the wind, and increasing or diminishing in all directions outward, it is arranged in lines which traverse the cyclone.[1] One of them which crosses the centre is merely an arbitrary line in a steep slope of temperature from south to north. The existence of such a dividing line is almost conclusive evidence against the common view that the

[1] The reader should refer to this diagram in considering the description of the polar front on p. 154.

1910 January 28, 7 a.m.



CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
28·7	971·9	29·2	988·8	29·6	1002·4
28·8	975·3	29·3	992·2	29·7	1005·7
28·9	978·6	29·4	995·6	29·8	1009·1
29·0	982·0	29·5	999·0	29·9	1012·5
29·1	985·4				

The isotherms are for 20° F., 266·3 t.; 30° F., 271·9 t.; 40° F., 277·4 t.

FIG. 51.—Chart showing the Relations of Pressure, Wind, Temperature and Weather in a Cyclonic System.

Note the occurrence of snow in the northern part and of rain in the southern part of the cyclonic depression with its centre near Holyhead.

air in any part of a cyclonic area may be regarded as having described a considerable part of a revolution. In this particular case it seems unnecessary to spend time in arguing the obvious proposition that none of the warm air in the southern part of the cyclone is supplied from the north, and none of the cold air in the northern half of the cyclone has come from the south. Any rotation round the centre has stopped short of allowing the separate air currents to trespass on each other's grounds.

DIURNAL VARIATION

With regard to the distribution of temperature shown on the map, it is desirable to notice particularly the two areas of intense cold. They are quite local and are to be attributed in these two cases to the effect of radiation from land areas to the clear sky in a calm atmosphere during the long night. Probably we should find, if investigation were made, that they were not only restricted in area, but also limited in their vertical dimension. A captive balloon would almost certainly show that there was warmer air above the cold air-pool, and this suggests a remark upon the great difficulty that exists in dealing with temperature in meteorological work. As observed at a meteorological station, it is subject to great diurnal fluctuations on account of the exposure of the surface to the heat of the sun by day and of the loss of heat by radiation to the clear sky at night. It is, of course, not always sunny by day and not always clear at night. When it is overcast the diurnal variation is much less, but it still exists; the observed effect is a complex result to which the whole surrounding country, whether consisting of sea or land, or partly sea and partly land, contributes.[1] The diurnal change at a station in the middle of a continent is very large compared with that at an island station. On the sea itself there is practically no diurnal variation at all. In clear weather in England it may be as

[1] Mr. J. Y. Buchanan found a diurnal variation on Ben Nevis, in foggy weather when the observing station had been enveloped in mist for at least three days. Buchanan, "Trans. R. S. E.," vol. 39, No. 31.

great as 44° F., 24·4 t. (See Fig. 156, taken from "Second Report of the Meteorological Committee, 1907," p. 16.)

The diurnal variation affects a synchronous chart in a very special manner. The region of the daily weather map of the Meteorological Office extends from the Azores in Long. 28° W. to North Sweden in Long. 25° E., and the difference of longitude implies a large difference of local time and therefore of local temperature. Thus, when it is sunrise at Greenwich it is two hours before sunrise at the Azores and nearly two hours after sunrise at Haparanda. There are consequent differences of temperature which make a temperature chart for 7 a.m. a structure of very complicated meaning.

Associated with the diurnal variation of temperature there is an equally well-marked diurnal variation of wind velocity. The hourly averages show a marked decrease of wind velocity in the night hours as compared with the day hours. This noteworthy variation is attributed by Koppen and Espy to the mixing of the lower layers of the atmosphere by convection due to surface heating during the day. The average diurnal variation is practically oblitorated by the passing of a cyclonic depression during the night hours, and to that experience may be attributed the common sense of unrest that is associated with wind during the night.

Besides the diurnal variation of temperature there is the seasonal variation which is also a very complex resultant of a multitude of thermal conditions.

In endeavouring to deal with considerations of temperature in relation to barometric pressure we cannot help feeling the wish that there were some means of "correcting" the observations for local influences of surface which are shown in diurnal and other variations, somewhat in the manner in which pressure is reduced to sea level. But unfortunately we have at present no means of knowing what the magnitude of such a correction ought to be for any particular occasion, and the statistical result applicable to the average occasion does not help us.

By the contrast between the temperature of the southerly wind from the Bay of Biscay and the southerly wind from Central Europe the chart of January 28 suggests another point with regard to temperature, namely, that the temperature of any specimen of air depends largely upon the region from which it has come. A further complication is thus introduced into the interpretation of the distribution of temperature and its relation to pressure. We shall return to this point when we consider later on the details of the circulation of air in various pressure distributions.

ABERCROMBY'S STATEMENT OF THE PRINCIPLES OF FORECASTING

The general distribution of weather associated with a cyclone or with other typical groupings of isobars is very clearly set out by Abercromby, and I quote, therefore, his "Principles of Forecasting," p. 10 to p. 35. Exception may be taken to the generality of some of the statements for reasons which will be apparent from what is said in subsequent chapters, but they give the general ideas which have been employed in forecasting in the past thirty-five years, and they have therefore been quoted as Abercromby gave them.

"The intensity of a cyclone is measured by the maximum steepness of the gradient in any portion of it. If this exceed 0·02 inch per fifteen nautical miles, then the cyclone may be said to be of considerable intensity.

"By the expression the level of a cyclone is meant the barometrical reading at the lowest point. If the lowest point in the cyclone is above 29·9 inches, we may call it a high-level cyclone; if below that a low-level one.

"The life of a cyclone is measured by the number of days during which it can be traced on synoptic charts. The length of the life may be anything from a few hours to about twenty days. Any cyclone whose life is less than twenty-four hours may be called short-lived.

"Now for the details of wind, weather, temperature, etc., in different portions of a cyclone.

"The temperature is always higher in front than in rear: the warm air in front having a peculiar close, muggy character, quite independent of the actual height of the thermometer. The cold air in the rear, on the contrary, has a peculiarly exhilarating feeling, also quite independent of the thermometer.

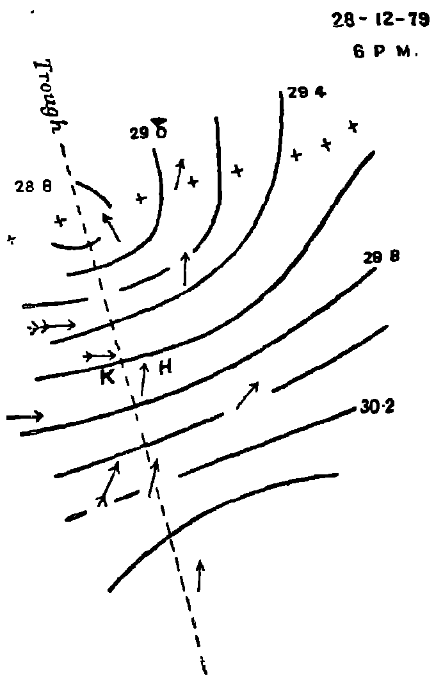


FIG. 52.—Chart of Isobars and Winds for the "Tay Bridge" storm of December 28, 1879. (Abercromby.)

"The front is always very damp, especially the right front, while the rear is dry to a marked degree.

"The wind blows round the centre in a direction contrary to the motion of the hands of a watch which is lying horizontally with its face upwards; but as the direction is slightly inclined to the isobars, on the whole the circulation is an ingoing spiral. The amount of incurvature is usually greatest

in the right front and least in the rear of the cyclone, so that sometimes the passage of the trough is marked by a sudden shift of wind. In Fig. 52 we give an illustration of exceptional incurvature. In the latter instance the wind at the point marked H is almost due south, while at K, some sixty miles off, it blows from the west, because the trough of the cyclone passes between the two places, whence it is evident that as the cyclone moves along its path, marked by the crossed line, the wind at the station H will shift suddenly from south to west, that is, eight points of the compass. This diagram gives the synoptic conditions of the United Kingdom 1¼ hour before the Tay Bridge was blown down by a violent gust. The chief interest of this species of incurvature is its bearing on the conception of a cyclone, for the sudden shift of wind was long held to be incompatible with a revolving storm. Now, by means of charts, we see how the two ideas are possible.

"There is reason to believe that the amount of incurvature is partly dependent on the velocity of the cyclone, but the reader must avoid the error of supposing that the wind in a cyclone is compounded of simple rotation and translation by the so-called parallelogram of velocities.

"The force of the wind depends almost entirely on the gradients. In the centre it is dead calm, and the steepest gradients are usually found at some distance from the centre. The direction from the centre in which the strongest are found depends on the position of the surrounding areas of high pressure, as will be abundantly illustrated further on.

"The relative steepness of the gradients measures the intensity of cyclones. Take, for instance, the cyclone shown in Fig. 15,[1] and conceive another of the same size and shape, moving in the same direction at the same rate, but in which the isobars, instead of representing a difference of 5 mb., represented a difference of only 2 mb., then we should have

[1] We have used the illustration of Fig. 15 instead of the one figured by Abercromby, and altered the text accordingly.

two cyclones differing in nothing except 'intensity,' which would be greater in the first than in the second; and what was actually a violent gale from nearly every point of the compass in some part of our islands would have been replaced by mere breezes from the same directions. Of course we cannot find such an instance in practice, but if, instead of Fig. 15, we had given an example of a cyclone of high level and very slight intensity, we should have found that the general nature of the circulation was identical, only differing in force. It is a fundamental principle of synoptic meteorology, that wind, and, as hereafter we shall show, weather also, depend on the shape and gradients but not on the level of the isobars. Later on we shall explain the import of a generally high—or low—level cyclone. From this we arrive at the important conclusion that there is *no difference between ordinary weather and a storm except in that property called intensity*, and that in this country a summer breeze and winter gale are equally the product of cyclones, which only differ in intensity. Hence, in forecasting storms, we have not only to foresee the arrival of a cyclone, but of one possessing sufficient intensity to cause a gale, and in tracking a gale it by no means follows that the same one causes a storm during every day of its existence. For instance, on August 14, 1873, a cyclone was formed a little west of the Cape Verde Islands, which passed as a hurricane round Bermuda, to Newfoundland by the 27th, after which it crossed the Atlantic and Great Britain as an ordinary cyclone, till it died out in Norway on September 2, and gave rise to nothing more than moderate breezes.

"Observation has also shown that a deepening cyclone is increasing in intensity, while one which is filling up is decreasing. Whence, in watching the progress of cyclones by telegraph, it is very important for forecasting to note changes in depth, as well as any other indication derived from the configuration of the isobars, or even from weather prognostics, which experience has shown to be associated with intensity.

"The broadest feature of the weather in a typical cyclone consists of an area of rain near the centre surrounded by a ring of cloud, but both the rain and cloud extend further to the front than to the rear of the centre, as in Fig. 53. When we come, however, to examine the nature of the cloud and rain as well as the general appearance of the sky, we find that the cyclone is also divided into two well-defined halves by the line of the trough. The front may be further divided into

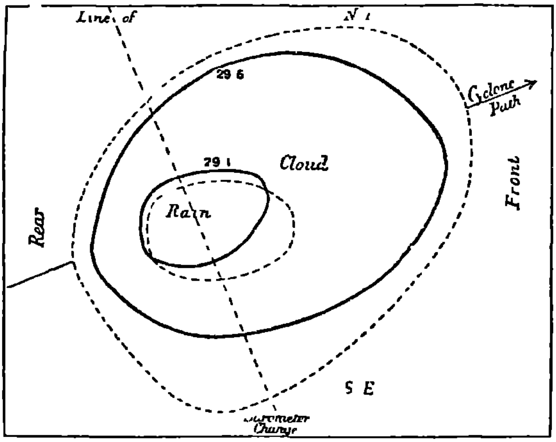


FIG. 53.—General Distribution of Rain and Cloud with reference to the Closed Isobars of a Cyclonic Depression. (Abercromby.)

the right or south-east and left or north-east fronts, which, though they have much in common, are sufficiently different to be classified separately. They are separated by the line which represents the path of the cyclone; but this line does not mark the position of any great physical change, like the trough, as the weather in either front merges gradually into the other. In Fig. 53 this is shown in a diagrammatic form, with lines marking out the position of the right and left, or south-east and north-east fronts, as well as the front and rear of the cyclone, besides showing the relation of the isobars to the rain and cloud areas. The whole of the front is generally characterised by warm, close, muggy

and damp weather, with a dirty sky, while the whole of the rear is cool, brisk, exhilarating and dry, with a hard, firm sky. Coming now to more minute detail, in the left or north-east front, when the steepest gradients are somewhere south of the centre, the first symptoms of the approach of a cyclone are a halo with a gradual darkening of the sky, till it becomes quite overcast, without any appearance of the formation of true cloud; or else, light wisps or barred stripes of cirrus,

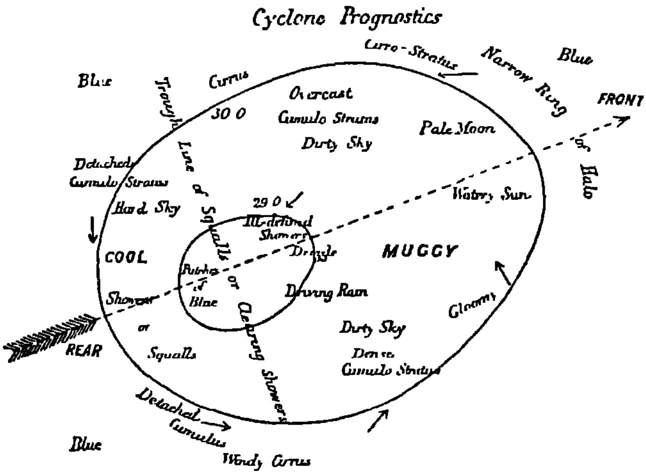


FIG. 54.—Details of Cloud and Weather in the Region of a Cyclonic Depression.[1] (Abercromby.)

moving sideways, appear in the blue sky, and gradually soften into an uniform black sky of a cumulo-stratus type; nearer the centre, light, ill-defined showers fall from the uniformly black sky, the wind from some point between south-east and north-east blows uneasily, and though the air is cold and chilly there is an oppressive feeling about it These appearances continue till the barometer commences to rise, when the character of the weather at once begins to alter. In a cyclone where the steepest gradients are somewhere to the

[1] Among the cloud forms in the diagram will be found the name *cumulo-stratus* which is no longer used. In its pictures it was represented as two types of cloud seen together, one a cumulus of threatening appearance and the other a detached lenticular cloud in front of the cumulus.

north and east of the centre, the general character of the weather is the same as above described, but is much more intense, the wind rising at times to a heavy gale and the ill-defined showers developing into violent squalls.

"In the right or south-east front, when the steepest gradients are to some point south of the centre, which will be seen further on to be the commonest case in this country, the first symptoms are likewise a gradual darkening of the sky into the well-known pale or watery sky, with a muggy, oppressive air; or else, as in the north-east front, wisps of cirrus first appear in the blue sky which gradually become heavier and softer till the sky is uniformly overcast with a cumulo-stratus type of cloud. Nearer the centre, rain, usually in the form of drizzle, sets in, and the wind, from some point between south-east and south-west, varying in force according to the steepness of the gradients, drives the cloud and rain before it. But this wind differs from that in the other portions of the cyclone in its way of blowing, and, for the same velocity, does not raise so high a sea, or seem to bear so much down on the surface of the earth. In cases of very great intensity, the rain in this portion of a cyclone may come in showers, or even squalls, but the general character is never lost.

"The line of the trough marks out a line of heavy showers or squalls, especially the portion on the southern side of the centre.

"The general character of the west or rear side, is a cool, exhilarating feeling in the air, with a high, hard sky, of which the tendency is always to break into firm, detached masses of cloud. The rain, which occurs near the centre, is usually in cold, sharp, brisk showers, or hard squalls, and the general hard look of the weather presents a marked contrast to the dirty appearance of the weather which characterises the whole front of a cyclone. Further from the centre, showers or squalls are replaced by simply detached masses of cloud, and these finally disappear, leaving a blue sky. The wind, from

some point between west and north, blows gustily, and for the same velocity raises a higher sea than a south-west wind, and seems to bear down more on the surface of the water. The whole of the rear of a cyclone partakes of this general character, but the change of weather along the north of a cyclone is not nearly so strongly marked as along the southern portion.

"If instead of the general terms 'rain,' 'cloud,' etc., used in Fig. 53, we write down in popular language the details of the kind of cloud or sky, with other characteristics of different portions of the same cyclone, as in Fig. 54, we shall find our old friends the popular weather prognostics of ordinary life, under a very new guise. We shall see that a large number of well-known prognostics of rain or bad weather are simply descriptive of the weather in different parts of a cyclone, and that they owe their value to their appearance in front of the rainy portion of a cyclone. Thus, a watery sky is a sign of rain, because it is a characteristic of the front or east side of a cyclone, and as a cyclone usually travels eastwards, an observer will successively be subjected to the influence of the cloudy and rainy parts of the cyclone before an area of fine weather again reaches him.

"Though the general characteristics of a cyclone—warm, muggy, and dirty weather in front; cool, dry and bright in rear—are invariably maintained, still individual cases vary much in detail.

"The sources of variation are so important that it will be necessary to examine them shortly, premising that they only modify, but do not alter, what we have called the general characteristics, and that though we are now referring only to cyclones, these variations apply to every other shape of isobars.

"There are six sources of variations which must be mentioned, viz., 1. the type; 2. the intensity; 3. the size; 4. local variation; 5. diurnal variation; and 6. seasonal variation.

"The first source of variation in any cyclone is one which will be hereafter very fully developed, and which depends on the *type of general distribution of pressure to which it belongs.*

"The commonest type of cyclone in this country has the highest pressure at some point south of the centre, on which side the steepest gradients are found. In this case the rain and cloud area extends far to the south and south-east of the centre, but comparatively little to the north and north-west, while the hardest weather generally is found to the point of south, where the steepest gradients are. This may be termed the westerly type of cyclone, both because the paths of the cyclones run nearly east and west, and because the prevailing winds are westerly. In another less common type the highest pressure is some point to the north-east of the centre, on which side the steepest gradients are to be found; in this case the rain and cloud area is very differently shaped from that just described, extending furthest from the centre in the north-east direction, while the hardest and most severe weather is found to the point of north-east, where the steepest gradients are. This may be termed the easterly type of cyclone.

"It may be well to mention here that it is very rare to find rain at any particular hour over the whole of what is called the 'rain area'; but where not actually raining, the sky is overcast and bordering on rain, which is sure to fall some time during the day. Similarly in the area of less cloud, called the 'cloud ring,' isolated patches of rain are often found developed by local or other circumstances.

"The next source of variation depends upon the difference of the *intensity* of the cyclone. In cyclones of the same type the weather differs much in 'hardness,' or 'severity,' or in 'quietness.' Thus, in the south-east front the sky may be simply soft and overcast in a cyclone of moderate intensity, but with increased intensity the overcast sky would develop into soft, drizzling rain, or into broken rain, or even into a peculiar class of thunderstorm common on our west coasts in winter, while the wind would vary from a moderate breeze to a gale of any force. But in spite of these variations there is always the close, muggy atmosphere, and dirty sky character-

istic of this part of a cyclone. Again, in the rear, the general character is always a cool, brisk feeling in the air, with a bright and broken sky, which varies according to the intensity from simple heavy masses of cloud, to hard showers, to squalls, or to hail squalls with thunder and lightning; but no difference of intensity can ever alter the fundamental difference in the general character of the south-east front and the rear portions of a cyclone.

"Now it is found from observation that these differences of intensity are directly connected with differences of steepness in the barometric gradients. If, for instance, we take two cyclones, differing in nothing but a greater or less steepness of the gradients, as in discussing wind, the corresponding differences of weather would be shown in a less continuous area of rain near the centre of the second cyclone, in a smaller extension of cloud round the rain, and in a less total rainfall all over the country during the cyclone's passage. Where squalls occurred in the first cyclone, they would be replaced in the second by brisk showers, and the weather generally would be more deficient in those properties to which the words 'hardness' or 'severity' are usually applied.

"It is well known that a deepening cyclone is increasing in intensity, while one which is filling up is decreasing, and Professor Loomis has shown that in the United States rain and cloud extend further from the centre in the former than in the latter case, and there is reason to believe the same rule holds good in this country, though it is hard to verify.

"A third source of variation depends on *the size and shape of any cyclone*, and is intimately connected both with the type and intensity. In very large cyclones the steepest gradients and the bad weather which accompanies them are always found at some distance from the centre. In small cyclones the heaviest rain usually surrounds the centre, and extends more or less to one side or the other, according to the direction of the nearest area of high pressure, and the steepest gradients.

"Another very important cause of modification in weather is *local variation*. It is well known that in any storm, showers, squalls and thunderstorms are very local, and in some places, either from the contour of the ground or other causes, they are much more frequently developed than in others. Again, with the amount of rainfall, the position of ridges of hills, or of the sea, relatively to the prevailing winds, or the presence of lakes and forests as compared with bare ground, all seem to have an important influence over it. So important is the position of the sea, that on our east coasts the worst weather is with easterly winds, while on our south and west coasts the worst is with westerly winds.

"A fifth very important source of variation is one known as *diurnal variation*. This term is applied to changes in the amount of wind, cloud or rainfall which depend on the time of day. As a rule these changes are so complicated that they cannot be detailed in such an elementary work as the present, so that we must content ourselves with merely stating some important principles connected with them. The simplest conception of diurnal change can be got from the idea that though a day may be described in general terms as 'hot' or 'cold,' still there will be a diurnal range of the thermometer overriding or superimposed on the general temperature of the day. We have already alluded to the diurnal variation of wind, and it may now be stated generally that every meteorological element has a diurnal variation, that different shapes of isobars have not the same variation—for instance, the diurnal change of weather of a cyclone is almost the converse of that in an anticyclone; but that in every case the diurnal weather modifies, but does not alter the general character imposed on the weather by the shape of the isobars. The changes of weather due to alterations in the shape of the isobars are called the *general changes*, and it is a fundamental principle of synoptic meteorology that the diurnal variations and general changes are independent, and that the observed weather represents their sum. Therefore, though very

interesting from a purely scientific point of view, it follows that this variation plays no part in forecasting.

"The sixth and last source of modification is the seasonal variation. In this country, during winter, the cyclones are usually much larger than in summer; and, even in cyclones of about the same size and intensity, the position of the rain and cloud areas is not quite the same. In winter time, the clouds and general appearance of the sky are usually softer than in summer, and the rain is more drizzly and less showery,

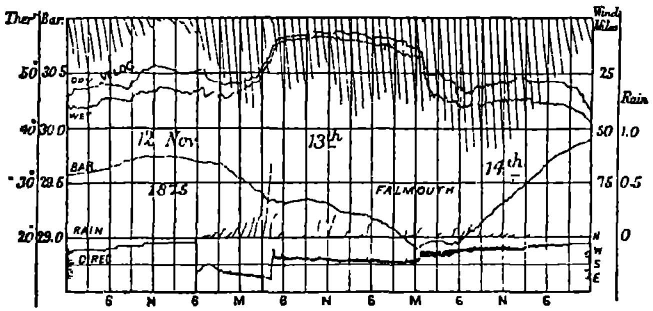


FIG. 55.—Meteorogram for Falmouth, November 12—14, 1875. (Abercromby.)

besides many other smaller differences, which are too well known to require minute description. This variation is an important factor in forecasting.

"From all these considerations we conclude that though every detail of weather is subject to assignable laws, the details are so complicated that we can describe the weather associated with any shape of isobars in general terms only.

"So far we have only dealt with a single synoptic chart, but as the isobars are constantly shifting their position, we see that a series of synoptic charts is simply a series of plans of the changing positions of atmospheric movements. While, therefore, a single chart tells us only about existing weather at a given hour, the comparison of two or more enables the direction, nature and succession of the ceaseless changes of cyclones to be accurately followed. As the aim of forecasting

is to foretell the weather changes at any one place, we must now endeavour to explain how the movements shown on a series of synoptic charts would be reflected as the sequence of weather at any place.

"The method employed, besides noting verbally the succession of physical changes in the appearance of the weather, such as blue sky, halo, cloud, rain, and blue sky

1875. November 13, 6 p.m.

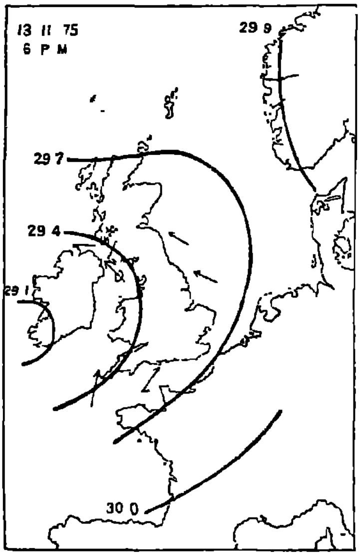


FIG. 56A.

1875. November 14, 8 a.m.

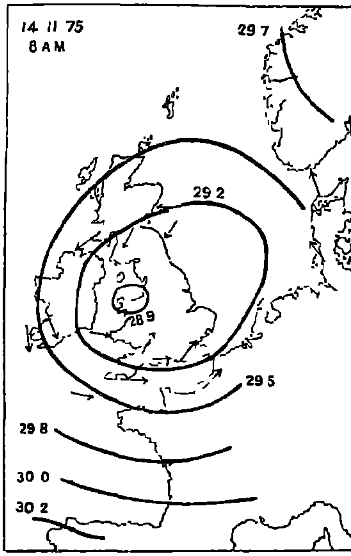


FIG. 56B.

Isobars and Winds of a Travelling Cyclonic Depression. (Abercromby.)

again, is to record in a diagrammatic form the changes in the readings of the different instruments which it is thought necessary to observe. The best traces are those obtained from self-recording instruments. The trace given by a barometer is called a 'barogram,' that by a thermometer a 'thermogram,' while a trace of either the direction or force of wind is called an 'anemogram.' When two or more of these traces are all combined in one picture, as in Fig. 55,

the whole is called a 'meteorogram.' For the sake of distinctness we also give in Figs. 56A and 56B small charts for a portion of the period contained in the meteorogram, so that the relation between the two kinds of observations may be easily detected. The specimen here given is one of those issued by the Meteorological Office.[1] Though, as will be seen hereafter, these traces are not of much use for direct forecasting, they are of the utmost value in following the progress of storms whose synoptic plans can only be taken at intervals, as well as for working out questions relative to the diurnal variations of all the meteorological elements, and other points which cannot be studied otherwise. The descriptive records give minute information as to the kind and shape of cloud, or quality of wind, and other details which cannot well be shown on a synoptic chart. In practice it is often very difficult to trace the manner in which changes of weather shown on the charts are reflected in the indications of the self-recording instruments, and to realise the influence of one on the other, but it can be done in most cases.

"A clear conception of the manner in which the motion of a cyclone as shown on a synoptic chart will affect the sequence of weather as it appears to a solitary observer, is of such importance that we propose devoting a few paragraphs to the consideration of the diagrams we have just referred to. In Figs. 56A and 56B we give two successive charts of the same cyclone at 6 p.m., November 13, 1875, and at 8 a.m., November 14; while above we give in Fig. 55 a meteorogram at Falmouth for three whole days, November 12, 13, and 14, 1875. In Fig. 57 the isobars and wind arrows for the chart in Fig. 56B are given on a larger scale.

"The first important point to remark is that as the cyclone moves along its path, it carries its own circulation of wind along with it. If, then, as in Fig. 57, we draw a line EG,

[1] The traces of the self-recording instruments at the seven observatories connected with the Meteorological Office have been reproduced in the Quarterly Weather Reports for the years 1869 to 1880.

passing through F, which represents the position of Falmouth, parallel to AB, the crossed line which marks the path of the cyclone, we shall get the sequence of barometric and wind changes at Falmouth. For instance, starting from E, the barometer would fall till we arrive at the trough, as we see in the right-hand half of the barogram in Fig. 55; after the passage of the trough, the barometer begins to rise. Note,

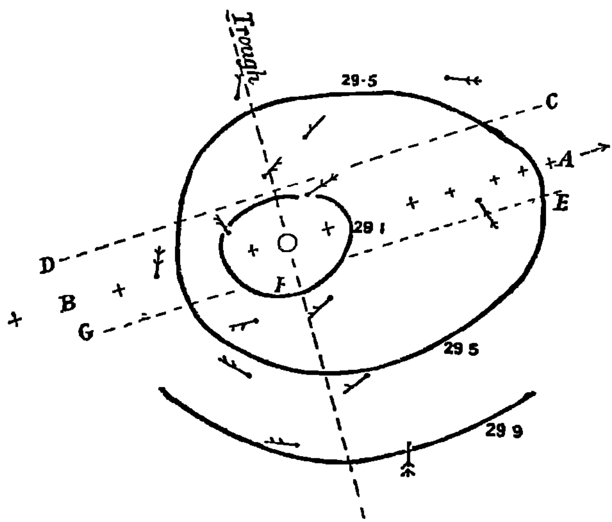


FIG. 57.—Sequence of Wind and Weather on the Passage of a Cyclonic Depression. (Abercromby.)

however, the sharp irregular dip of the trace just as the trough passes, for this is most characteristic, and is associated with the squall already mentioned as occurring in this portion of a cyclone. As in this case the gradients are steeper in rear than in front of the cyclone, the rise of the barometer will be more rapid than the fall. Turning now to the wind direction, we see from the chart, Fig. 57, that the wind will be from between south-south-east and south in front of the trough when it will suddenly shift about six points of the compass to west-south-west, and then veer

slowly towards the north-west. All this is well shown in the direction anemogram. Then as to velocity, a glance at Fig. 56B shows that the gradients are less steep in front than in rear, and by reference to the velocity trace, Fig. 55, we see that the greatest velocity of the wind was not attained until after the barometer had begun to rise. If the station had been somewhere north of the cyclone centre, we see by the reference to the line CD, Fig. 57, that the shift of wind would have been from south-east by north-east, and north to north-west; also that on either side, the nearer a station is to the centre, the greater will be the shift of wind.

"On the south side we have seen that the wind shifts in the same direction as the motion of the sun, which is called 'veering'; while on the north side it shifts against the sun, which is called 'backing.'[1]

"Turning now to the sequence of weather, if we consider how any single station would be affected by the passage of the cyclone in a manner similar to the shifts of the wind, we find that the cyclone carries its characteristic weather along with it, and that therefore the sequence to a solitary observer would be from blue sky through a ring of cloud, then through rain, then more cloud, and finally to blue again. We also see that if he was a certain distance from the centre he might only experience a period of cloud without any rain. Returning now to our prognostic diagram, Fig. 54, in which we have generalised the actual cyclone given in Figs. 52, 56A, 56B, and 57, we see at once that if we draw a section across it south of the centre, as we did for wind, we shall get a sequence of 'halo,' 'gloom,' 'muggy weather,' 'uneasy animals,' 'drizzling rain,' 'driving rain'; then at the passage of the trough we shall have a squall or shower, then the sky begin-

[1] "Veering" and "backing" are now officially defined as the changing of wind with clock hands or against clock hands. It is only in the northern hemisphere that the wind veers with the sun and backs against the sun. In the southern hemisphere the reverse is the case.

ning to break, with showers and cumulus cloud till the sky is blue again. These changes were very clearly observed by the author (Mr. Abercromby) during the passage of the cyclone shown in Fig. 56A over Brighton.

"Thus we see that to get an idea of the sequence of weather from a synoptic chart, we must draw a section across a cyclone parallel to the direction of its motion; and that the relation of the two may be expressed in statement,—a meteorogram or a series of consecutive observations on the changing physical appearance of the weather at a single place, for any given interval, may be considered as a continuous record *in section* of that weather, while a series of synoptic charts, at definite intervals of time, shows the same changes *in plan*.

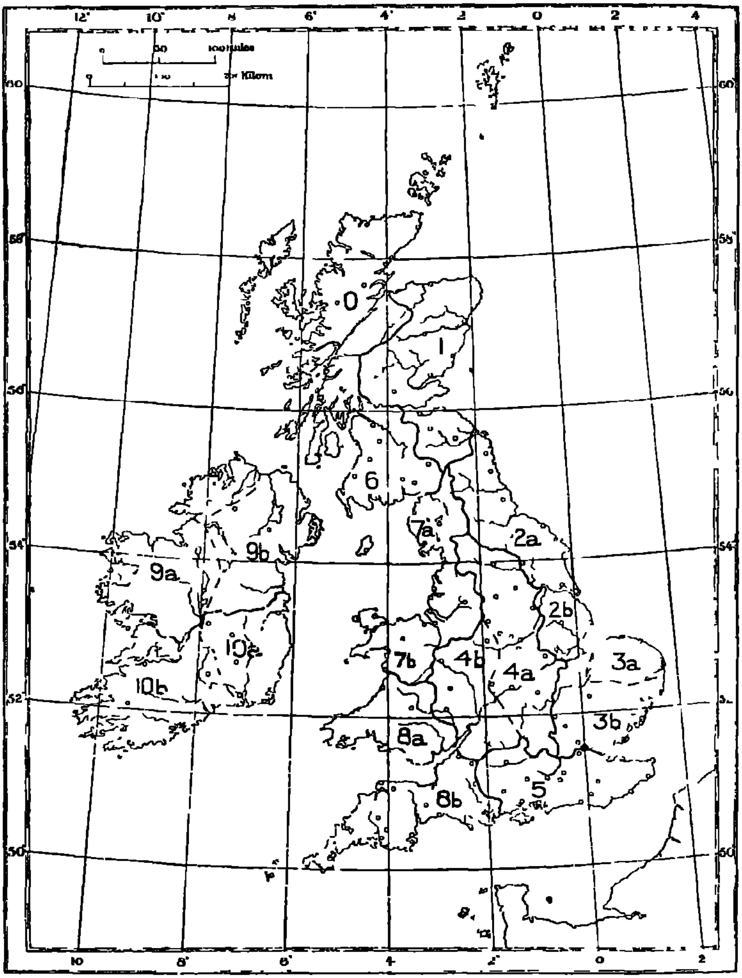
"Taking only cyclones, we see that if they remain pretty constant in shape, and move pretty regularly along a given path, then we can forecast the weather which will accompany their passage very accurately. Unfortunately, as a rule the same cyclone varies very much in shape at different periods of its existence and moves along a very irregular path, at very different rates, so that the forecaster is doomed to many failures and disappointments."

This subject may be studied by examining the records for any characteristic cyclonic depression. We may refer here to the diagram of p. 63, which was reproduced with reference to the depression of February 27, 1903.

THE PRACTICE OF FORECASTING

Upon the general principles thus established the modern method of forecasting is based. It is the business of the forecaster to determine what type of barometric distribution is to be expected within the next twenty-four hours, and to assign to it its appropriate weather. It generally happens that the conditions anticipated are not the same for the whole country. A very striking case in illustration is represented in Fig. 51 which gives the chart for January 28, 1910, when the

FIG. 58.—Map of the British Isles showing Forecast Districts until 1919.



a. Scotland, North. Islands.
b. „ „ Mainland.
Scotland, East.
a. England, North-East. Northern Section.
b. England, North-East. Southern Section.
England, East.
a. Midland Counties. Eastern Section.
b. Midland Counties. Western Section.
England, South East, with London and Channel.

6. { a. Scotland, West.
b. Isle of Man.

7. { a. England, North-West.
b. North Wales.

South Wales.
England, South-West.

9. { Ireland, North. Western Section.
b. Ireland, North. Eastern Section.

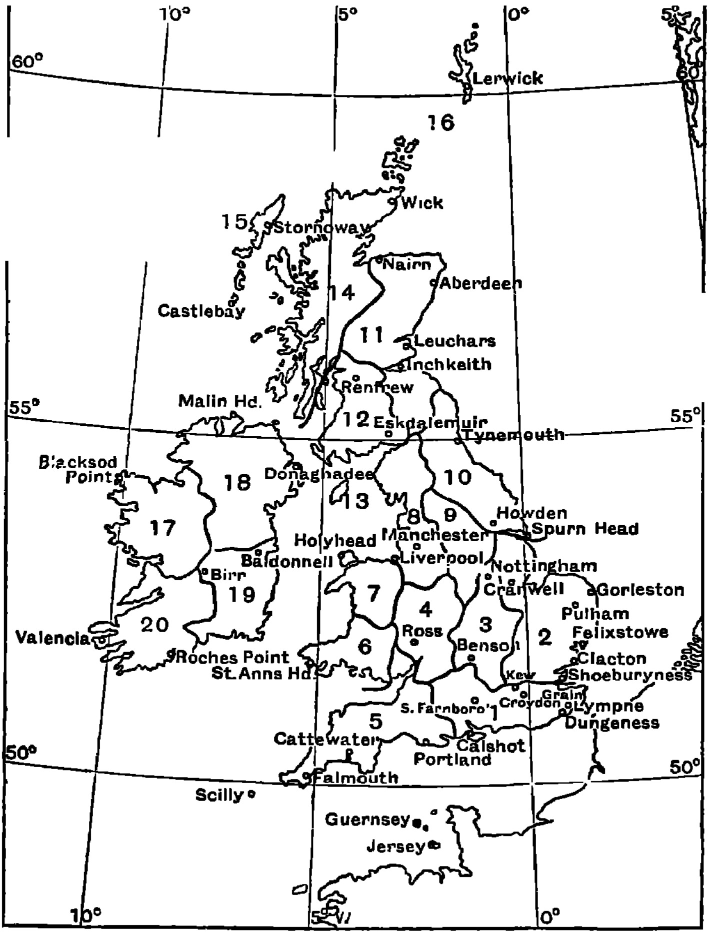
10. Ireland, South. Eastern Section.
b. Ireland, South. Western Section.

southern half of England was covered by warm southerly winds and rain while the northern part of England and part of Scotland was exposed to cold winds and snow storms; further north it was calm, clear and cold. In order to enable the forecaster to draw a distinction between the different parts of the country a division into districts is made. The districts are represented on the accompanying map (Fig. 58) and the more recent version of it (Fig. 59). In view of such conspicuous differences north and south of the line of passage of the minimum, the forecaster must be prepared to estimate the direction in which the distribution of pressure will travel, so that he may distinguish between the right and left sections of a cyclone; he must also form an opinion of the speed of travel, so that he can allow for the passage of the trough and the difference between the experiences of the front and the rear.

Specimen forecasts, as issued for Friday, June 24, 1910, are given in the table on p. 151. It is to be remarked that by rule of the Meteorological Office, the forecaster must always give in writing the reasons upon which he bases his forecasts, and therefore the official issues of forecasts are always preceded by remarks upon the general situation as disclosed by the series of telegraphic reports upon which the forecasts are based and represented upon the chart and by a statement of the "general inference" drawn from the observations. The detailed forecasts are merely the application of the general inference to the several districts.

A more recent specimen (p. 152) taken from the British Section of the Daily Weather Report for 1921, September 28, may illustrate the changes that have been introduced into the practice of forecasting within the past ten years. The most notable feature is the definiteness of the anticipations in the further outlook which may be attributed to the more effective organisation for referring the current situation to corresponding types of previous dates. The subject will be referred to again in the next chapter (p. 173).

FIG. 59.—Map of the British Isles, showing Forecast Districts in use from April 1, 1919.



1. S.E. England.
2. E. England.
3. E. Midlands.
4. W. Midlands.
5. S.W. England.
6. South Wales.
7. North Wales.
8. N.W. England.
9. N. Midlands.
10. N.E. England.
11. E. Scotland.
12. S.W. Scotland.
13. Isle of Man.
14. N. and N.W. Scotland.
15. Hebrides.
16. Orkneys and Shetlands.
17. N.W. Ireland.
18. N.E. Ireland.
19. S.E. Ireland.
20. S.W. Ireland.

FRIDAY, JUNE 24, 1910.

GENERAL INFERENCE FROM THE 7 A.M. OBSERVATIONS.

There are no indications of any important change in the pressure distribution at present. The depression now over Ireland and the adjacent portion of the Atlantic is likely to move very slowly in an easterly direction.

WEATHER PROSPECTS.

		DISTRICTS.	FORECASTS FOR THE 24 HOURS. NOON FRIDAY TO NOON SATURDAY.	THE FURTHER OUTLOOK.[1]
0	a	Scotland North, Islands .	Wind between north-east and south-east, light or moderate; cloudy or dull, some rain, rather heavy in places; cool.	Changeable weather, with rather low temperature.
	b	Scotland North, Mainland		
1		Scotland East		
2	a	England North East, Northern Section . .	Southerly to south-westerly or westerly winds, light or moderate; much cloud, occasional rain, improving somewhat by to-morrow; rather low temperature	
	b	England North-East, Southern Section . .		
3		England E.		
4	a	Midland Counties, Eastern Section . . .		
	b	Midland Counties, Western Section . . .		
5		England South-East, with London and Channel .		
6	a	Scotland West	Same as Nos. 0 and 1.	
	b	Isle of Man		
7	a	England North-West .	Same as Nos. 2 to 5.	
	b	North Wales		
8	a	South Wales	South-westerly to westerly winds, light or moderate, fresh locally; cloudy or dull, some rain, then fair; cool.	
	b	England South-West .		
9	a	Ireland North, Western Section	Wind between south and west, but varying locally, light or moderate; rainy, then improving somewhat; rather cool.	
	b	Ireland North, Eastern Section		
10	a	Ireland South, Eastern Section		
	b	Ireland South, Western Section		
11		WESTERN CHANNEL AND BAY	Light or moderate winds between south-west and west; sea moderate or slight; some showers and mist, then improving.	

[1] If the conditions are such that no satisfactory indication of the weather beyond the 24 hours can be given, this column will be left blank.

WEDNESDAY, SEPTEMBER 28, 1921.

GENERAL INFERENCE FROM THE 7 A.M. OBSERVATIONS.

A very large anticyclone extends from several hundred miles westward of Ireland to Russia and shows no signs of giving way. Over the British Isles generally fair quiet weather is probable for the next few days, with little cloud in the south, but mist or fog at night.

WEATHER PROSPECTS

	DISTRICTS	FORECASTS FOR THE 24 HOURS COMMENCING [illegible] G.M.T.	FURTHER OUTLOOK
1	S E England	Light to moderate easterly winds fine mist or fog at night moderate day temperature with risk of ground frost at night	
2	E England		
3	E Midlands		
4	W Midlands		
5	S W England		
6	S Wales		
7	N Wales	Light indefinite to southerly breezes fair mist or fog at night moderate temperature with risk of ground frost at night	Mainly fair and dry weather probable over the southern half of the kingdom for the next week. Over the Eastern and Central parts of England and south of the Humber the chances are distinctly against a break up of these conditions within the next fortnight
8	N W England		
9	N Midlands		
10	N E England		
11	E Scotland	Light to moderate south westerly winds fair mist at night moderate temperature	
12	S W Scotland		
13	Isle of Man		
14	N and N W Scotland	Moderate westerly winds clouds to fair, visibility good, cool	
15	Hebrides		
16	Orkneys and Shetlands		
17	N W Ireland	Same as 7 to 10	
18	N E Ireland		
19	S E Ireland	Light to moderate south easterly winds fine mist or fog at night moderate temperature risk of ground frost at night	
20	S W Ireland		

LOCAL VARIATIONS OF WEATHER

If the forecaster is successful in his efforts to deal with the movements of the barometric distribution he will have fulfilled his duty, but he will not have utilised all the knowledge which we can bring to bear upon the question of anticipating to-morrow's weather. The districts are large and the orographical and topographical conditions of different localities within them are different. The forecaster in a central office cannot take account of the special conditions of a particular locality. In this matter local experience might be turned to great advantage if there were an organised method of ascertaining and codifying the local variations of weather under known general conditions. We shall devote one of our later chapters to the consideration of this aspect of the local application of forecasts, but before entering on that part of the subject we shall consider the question of the classification of types of weather. Meanwhile it may fairly be said that the general character of to-morrow's weather can generally be correctly anticipated, but a definite statement of how much, or, indeed, if any rain will fall in one particular locality, or at what particular hour it will fall is not yet within the normal range of official practice though it has become part of the regular duty of the Norwegian service through the activity of the Geophysical Institute of Bergen to which we now turn our attention.

THE POLAR FRONT IN TRAVELLING CYCLONES

An example of the possibility of such further development is to be found in the study of the relation of temperature and rainfall to distribution of pressure in a cyclonic depression by J. Bjerknes and his colleagues of the Geophysical Institute of Bergen. The most recent exposition of this study is the analysis of the causes of rainfall in Norway in a paper by J. Bjerknes and H Solberg entitled Meteorological Conditions for the Formation

of Rain" in "Geofysiske Publikationer," Vol. II., No. 13: *Utgit av den Geofysiske Kommission.* Instead of referring the phenomena of the cyclone to the centre as a single point of reference, which has been the practice heretofore, the authors of the paper divide the cyclonic area into two portions, very unequal

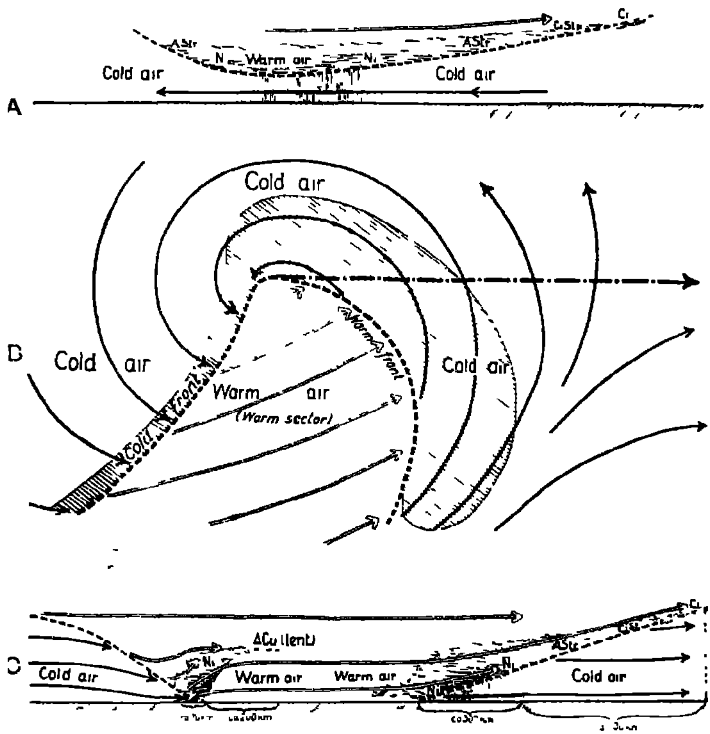


FIG. 60.—The Polar Front: B, plan: A, C, sections along lines north and south of the centre of an idealised cyclone. J. Bjerknes and H. Solberg.

The dotted line shows the polar front; the chain line the path of the centre.

parts, by two lines which meet at the centre. These two lines mark the boundary of a projection of warm air, generally from the southward, into a region of cold air; thus the whole area of the cyclone is divided into a warm sector and the cold remainder, instead of being divided as in the analysis of Abercromby and Marriott into front and rear and further subdivided into right and

left quadrants. The dividing line of the cyclone from the centre towards the eastern or advancing side is called the *steering line*, or more recently, *warm front*. In normal conditions it is marked by a rise of temperature, preceded by a considerable and prolonged fall of rain which is itself preceded by a succession of clouds beginning with *cirrus* and passing through the sequence of *cirro-stratus* and *alto-stratus* to *nimbus*. The boundary at the rear is called the *squall line* or, now, the *cold front*. It corresponds with the trough of the depression, and is marked by a sudden fall of temperature accompanied by a shower of rain.

This new analysis of the phenomena of the cyclone is represented in Fig. 60 and marks a considerable advance on the customary analysis in that it takes account not only of the distribution of cloud and weather, but also of the changes of temperature and the local distribution of rain. The ordinary rain areas are indicated by shading in the figure. The rain in advance of the warm front is attributed to the general ascent of the warm air from the line of the front, along a slope of about 1 in 100, over the bank of cold air, and the rain of the cold front is attributed to the undercutting of the warm air by the cold air in its rear with a somewhat steeper surface of separation. Rainfall in regions outside the two which are associated with the two fronts, apart from wet fog or drizzle, is attributed to the local instability of air passing over warmer sea or land. It is particularly prominent over the land in summer and over the sea in winter. Summer cyclones over land must therefore receive special consideration, but, that being allowed, it is claimed that all cases of rainfall in Norway can be identified as belonging to one or other of the following classes :—

1. CYCLONIC RAIN.—(*a*) *Warm front rain* formed in warm air pushing upwards along a retreating wedge of cold air.

(*b*) *Cold front rain* formed in warm air displaced by an advancing wedge of cold air.

2. INSTABILITY SHOWERS.—(*a*) Instability produced by heating from warm sea-surfaces.

(*b*) Instability produced by isolation over land (local showers).

3. "FOG-RAIN" (DRIZZLE).—Slight rain formed in low layers by cooling of air in contact with relatively cold sea- or land-surfaces.

4. OROGRAPHICAL RAIN.—Formed in air-currents ascending mountains.

The recognition of the special features of the distribution of rain and its relation to temperature places the forecasting of rain in Norway on a footing practically similar to that on which forecasting wind has been in this country; and, for those who have examined the corresponding phenomena for our area, should lead to a definite step in advance in the art of forecasting. Further study may lead to greater precision.

In other papers by V. Bjerknes and other members of the Norwegian school the cold mass of air which occupies the whole of the area of the cyclone with the exception of the warm sector is designated polar air and the warm sector equatorial air. The two fronts combined form a discontinuous boundary called the Polar Front between the general mass of the polar air on the northern side and the general mass of the equatorial air on the southern side, and the boundary between the two has been regarded as continued from cyclone to cyclone all round the northern regions. Thus we revert to cyclonic phenomena regarded as the results of the conflict of polar and equatorial currents, an idea inculcated by Dove in the middle of the nineteenth century. Instead of dealing with the motion of the centre of cyclonic systems we are invited to study the wrigglings of the polar front and the rainfall that is associated with points of singular contortion.

With that, however, we are not concerned in this chapter, as we are dealing now with the effective analysis of the cyclonic phenomena only; it will be referred to in Chapter X.

It will be noticed that there is a good deal of evidence in support of this analysis in the isothermal lines of the figures in this chapter and in the examples of the distributions of rainfall in Chapter IX. We are not yet in a position to say what final inferences are to be drawn from the evidence of discontinuity in various localities

and various levels. We may ultimately conclude that they are all part of a single surface of discontinuity contorted by the relative motion of the two fronts; but on the other hand we ought to remember that wherever convection is active there is discontinuity, no matter what the source of the air may be.

Looking at maps of the distribution of pressure over the globe, such as those represented in Figs. 9 and 10 of this work, it may perhaps be suggested that sufficient emphasis has not been laid on the fact that the principal regions of cyclonic depressions appear as troughs or extended lines of low pressure between more permanent and more extensive anticyclonic areas with notably different temperatures. We may thus put Dove's idea of the conflict of polar and equatorial currents, now expressed as the doctrine of the polar front, into modern language by describing it as the conflict between anticyclones of different temperatures of which the exterior bands form the opposing currents. Cyclones thus become a sort of skirmish of outposts of the more durable atmospheric structures.

CHAPTER VI

TYPES OF WEATHER AND THE FURTHER OUTLOOK IN WEATHER FORECASTING

HITHERTO we have confined our attention to the nature of the weather to be expected when a recognised barometric distribution has arrived or is in process of arriving. We have not supposed that the forecaster need possess more experience than that necessary to notice the first signs of the appearance upon his map of a group of isobars of recognisable shape, to estimate its line of march and to assign to it its appropriate weather. This is in itself sometimes a difficult process. The backing of the wind to the southward on the west coast of Ireland is often the first sign of the approach of a cyclonic depression from the Atlantic, and it has been used, times without number, as the first step in the formation of a successful forecast suggesting the fall of the barometer which almost invariably ensues. But there is little or nothing in these first signs of the approach of a depression to indicate whether a circular depression or a V-shaped depression is on the way, and this uncertainty has caused some notable failures. The forecast issued on January 31, 1910, furnishes a good illustration of this point. The backing wind and falling barometer of the morning map pointed to the arrival of a new depression which was expected to give gales in Ireland and north-west England; but with the advancing depression there spread out a wave of low pressure from Iceland, and the fall of the barometer on our western shores resulted in the advance of the northern part of a V-shaped depression, and consequently no strong wind, over the threatened areas. The V displayed further idiosyncrasy, for, contrary to the habit of V's which

generally move rapidly, it remained almost stationary from February 1 till February 4, and then incontinently disappeared from the map.

Such eccentric behaviour is exceptional, but to aid in the recognition of advancing pressure changes and, moreover, in order to use the experience of prolonged study of weather maps in anticipating changes beyond the immediate range of the forecaster's map, the general distribution of pressure over large areas has been classified into types by many workers in synoptic meteorology.

I approach the consideration of this part of the subject with more diffidence than any other. No one can work with weather charts for any long period, whatever the size of the area represented, without formally or informally grouping his charts into families. Some of them will have very marked family likeness and there will be no doubt about their being typical. Long experience will teach the handling of the types in such a way as to be of real assistance in forecasting. But to cast the knowledge into a form of words that will convey enough, but not too much, meaning for any reader who has not a very large experience of weather charts is a task that would lead to tedious and unproductive detail. So many of the barometric distributions are sufficiently different from the pronounced family types to make one hesitate to include them therein, that I find myself with a vast number of examples which I must label "transitional." When one considers that every form of distribution incidental to the transition between the different principal types is possible, it is evident that the transitional class will be numerous; and, moreover, in individual cases a distribution of a transitional type demands more consideration than one of well recognised character, and is in that sense more important.

Further, the system of classification which will commend itself to the reader must depend to no small extent upon the area of the region which his maps bring under review. With an extended area one forms a different mental picture, and

features which are important on the trivial scale lose their importance when the view is widened.

Abercromby gives four well-marked types of weather—the southerly, the westerly, the northerly, and the easterly—which I propose to illustrate in turn by maps of the North Atlantic. Since Abercromby's principles were formulated the North Atlantic has been much more extensively mapped than it was in 1885. We have now (up to 1910) a series of daily synoptic charts published since January, 1881 (omitting August, 1882, to August, 1883) by the Danish Meteorological Institute and the Deutsche Seewarte jointly, in continuation of those prepared by Captain Hoffmeyer, of the Danish Institute for the period from September, 1873, to November, 1876. The Deutsche Seewarte, moreover, published a daily synoptic chart of the Atlantic in small scale in its "Dekadenbericht," only a few weeks after the dates represented. There are besides charts of the northern hemisphere issued for the years 1878 to 1884 by the United States (Signal Service), and in 1886 the Meteorological Council published a most complete and detailed series of daily charts of the North Atlantic for the thirteen months from August, 1882, to August, 1883. This was a year of special circumpolar investigation, during which a large number of stations were maintained by international enterprise in north polar regions. I think I am expressing the experience of others as well as myself when I say that the publication of this most valuable series of charts has been destructive of any hope of simple rules for weather sequence or for the movement of high and low pressure areas. The atmosphere over the North Atlantic is shown to be throughout the year in a state of turmoil which defies simplicity of description, and it is clear that something more than a process of classification is required before the sequences will become amenable to formulated law.

At the same time everybody will recognise the family likeness of the isobaric distributions which belong to Abercromby's weather types. I have selected examples to illustrate them

partly from the synchronous charts of the North Atlantic in the year 1882–3, and partly from the "Tagliche Synoptische Wetterkarten fur den Nordatlantischen Ozean," already referred to, and I have taken some illustrations also from a series of charts of the North Atlantic produced by the Meteorological Council in 1901 to illustrate the remarkable stormy winter of 1898–9. The occasions which I have selected for illustration are those which have become historical on account either of the long persistence or the intensity of conspicuous examples of weather, such as prolonged and intense frost in winter or persistent succession of rainy depressions.

SOUTHERLY TYPE

The first example, that of the southerly type (Fig. 61), represents a strong southerly current over the British Isles forming the eastern boundary of a deep low pressure system. A high pressure system over Scandinavia apparently blocks the further advance of the general westerly surface current of air over the Atlantic and turns it northward. The name is derived from this transverse current, as it may be called. The anticyclone over north-eastern Europe is a substantial reality which has a southerly current on its western side, but it is doubtful whether any considerable portion of the air which formed that current came from the west. The study of "The Life History of Surface Air Currents" shows that a southerly current is generally a short-lived affair. It is usually on its way to the central region of a depression where it disappears. Its place is generally taken by a colder current of different air from the west, and the phenomena of the passage of the trough of a cyclonic depression are generally related to the replacement of the southerly current by the westerly current. On the other hand the eastern side of the southerly current often takes its rise, as in the case of January 28, 1910, already quoted (Fig. 51), from the south-east. In the winter this part of the current is cold; it represents the permanent western side of the anticyclonic area and

feeds the northern side of the low pressure area. Upon the strength and volume of this current probably depends the question whether the anticyclone will hold its ground or give way.

Many persons will still remember the long period of frost of February, 1895, the latest period of prolonged cold in this

1882. November 15, Noon G. M. T.

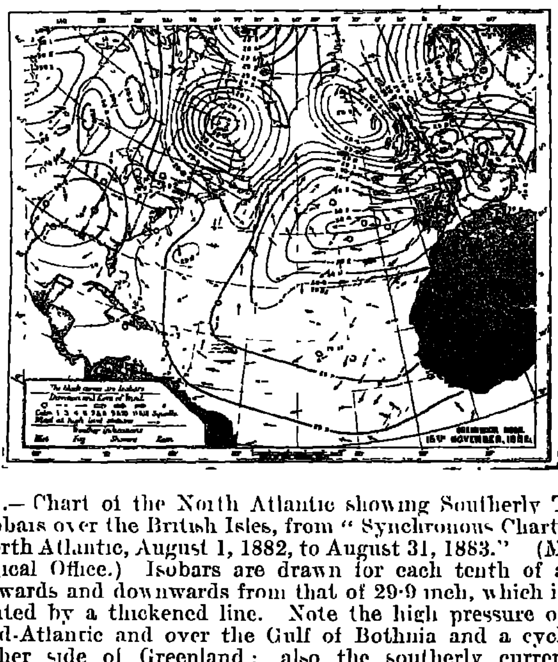


FIG. 61.—Chart of the North Atlantic showing Southerly Type of Isobars over the British Isles, from "Synchronous Charts of the North Atlantic, August 1, 1882, to August 31, 1883." (Meteorological Office.) Isobars are drawn for each tenth of an inch upwards and downwards from that of 29·9 inch, which is represented by a thickened line. Note the high pressure over the mid-Atlantic and over the Gulf of Bothnia and a cyclone on either side of Greenland; also the southerly current over Britain, the western part of which belongs to the circulation of warm Atlantic air round the low pressure, and the eastern part to the circulation of cold continental air round the "high" over Bothnia.

country (see p. 165). Figs. 62 and 63, February 14 and March 8, taken from the Danish-German charts, have been selected to illustrate that period; they show clearly the alternatives of the cold southerly type and the warm southerly type. In the latter the continental anticyclone has receded

1895. February 14, Forenoon.

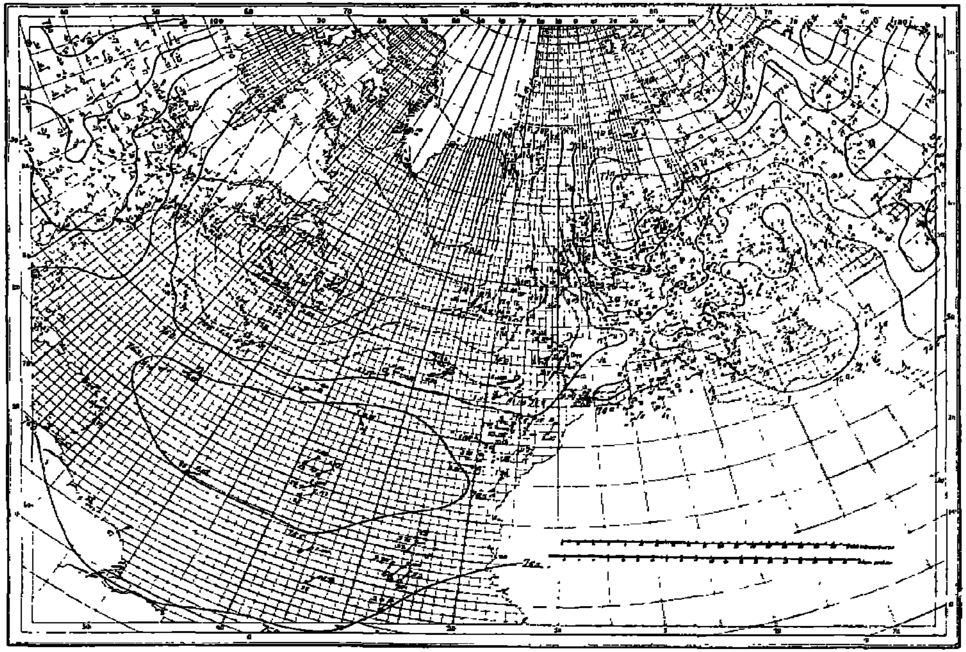


Fig. 62.—Synchronous Chart of the North Atlantic from "Tägliche Synoptische Wetterkarten für den Nordatlantischen Ozean," illustrating the Cold Southerly Type during the period of prolonged Frost of 1895.

Explanation.

Isobars are drawn for 760 mm. and for steps of 5 mm. above and below that figure.

Isobars for pressure below 760 mm. are shown by broken lines.

Temperatures are given in the Centigrade scale.

Winds are represented in direction by the direction of arrows drawn *to* the point of observation, and in force by the "feathers" at the tail of the arrow. A short feather counts one, a long one two on the scale. Thus ǀǀ̲ represents a wind of force 3; ǀǀǀ̲ a wind of force 6.

5 March 8, Forenoon.

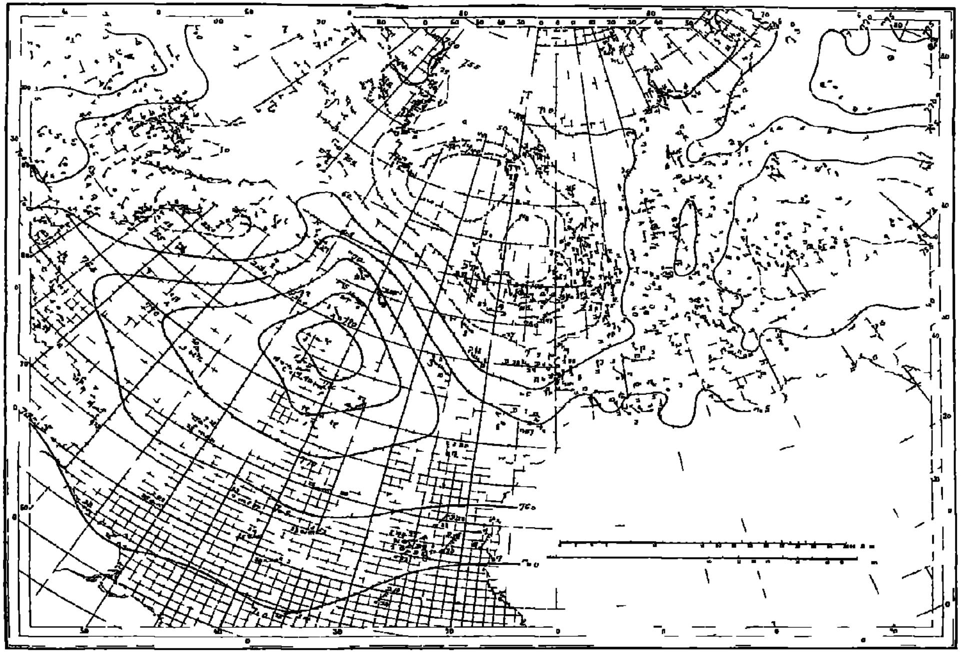


Fig 63.—Synchronous Chart of the North Atlantic from the "Tägliche Synoptische Wetterkarten für den Nordatlantischen Ozean" showing the Transition from Cold Southerly Type to Warm Southerly Type

NOTE.

For the explanation of the symbols on the chart see p 163

Note the region of low pressure (broken line isobars) within the area of the isobar of 760 mm enveloping the British Isles

The whole of the southerly current over Britain in this case consists of warm Atlantic air, whereas in Fig 62 it consists partly of very cold continental air.

somewhat, and the westerly current has invaded our islands and replaced the cold southerly current of February 14 by a warm southerly current. This is the chart that marked the final break up of the long frost.

WESTERLY TYPE

The two examples of a westerly type of weather (Figs. 64 and 65) are taken from the "Charts Illustrating the Weather of the North Atlantic Ocean in the Winter, 1898–9." The period was marked by a succession of severe gales over the Atlantic Ocean, which caused unusual delay and damage to the shipping crossing that ocean. Public interest was specially aroused by the prolonged anxiety as to the safety of two important transatlantic steamers, the *Pavonia* and the *Bulgaria*, both of which were disabled by the severity of the weather. The period was also remarkable for the warmth experienced on the eastern shores of the Atlantic, while over the American continent the weather was exceptionally cold. The two charts which I have selected show a strong westerly current, 600 to 1,000 miles wide, crossing the Atlantic and having a number of low pressure areas on its northern fringe. This distribution is characteristic of a great deal of the persistent unsettled weather which we sometimes experience for weeks or even months together. The dominant westerly current invaded and contorted by cold air currents from the north is very well illustrated by the succession of charts to which reference has been made, and from which these two examples have been taken.

NORTHERLY AND EASTERLY TYPES

The next illustrations (Figs. 66 and 67), representing the northerly and easterly types, are also taken from the "Tagliche Synoptische Wetterkarten" for 1895, the year of the very long spell of intensely cold weather which lasted during the whole of the month of February. They are selected

to indicate the conditions under which "freezing" weather becomes possible in these islands. Fig. 66 represents a cold northerly current coming from the Arctic regions, which in the form of a northerly or north-westerly wind may freeze the whole surface of our islands. The coldest winds are often the north-westerly, though there are north-westerly winds which are of a different character. Fig. 67 shows a very well pronounced easterly type, with isobars ranging east and west over a large part of the map, guarding an anticyclone to the north of us. This is the distribution most favourable for a long frost, when the air supply comes persistently from the cold continental area. The frost is confined to the eastern parts of our islands if the anticyclone does not extend much beyond the continental area.

OTHER TYPICAL DISTRIBUTIONS

To these examples of the types named by Abercromby I have added one of a north-easterly type (Fig. 68), and one of a south-westerly type (Fig. 69) from the synchronous charts of the North Atlantic. These differ but little from the easterly type and the westerly type respectively. I have added them because they represent the conditions of our two most persistent winds, the south-westerly and the north-easterly. The tracing pens of our self-recording anemometers hang generally either between S.W. and N.W. or between S.E. and N.E. Winds in the other quarters are, comparatively speaking, transient.

The types of isobars which have been reproduced represent the chief atmospheric currents with which we have to reckon in these islands. They comprise the travelling depression as a more or less important incidental item. It is evident that they are closely related to the general distribution of pressure. The westerly or south-westerly type arises when the tropical anticyclone of the Atlantic extends northward and eastward to south-western Europe, so that its northern slope covers the British Isles. On these occasions there is often practical

1899 January 15, Local Noon.

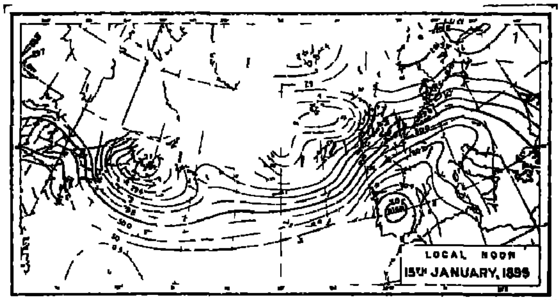


FIG 64.—Westerly Type.

1899. January 16, Local Noon

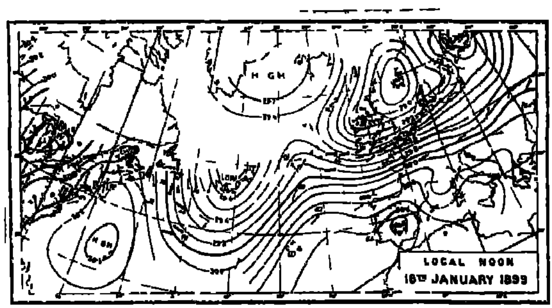
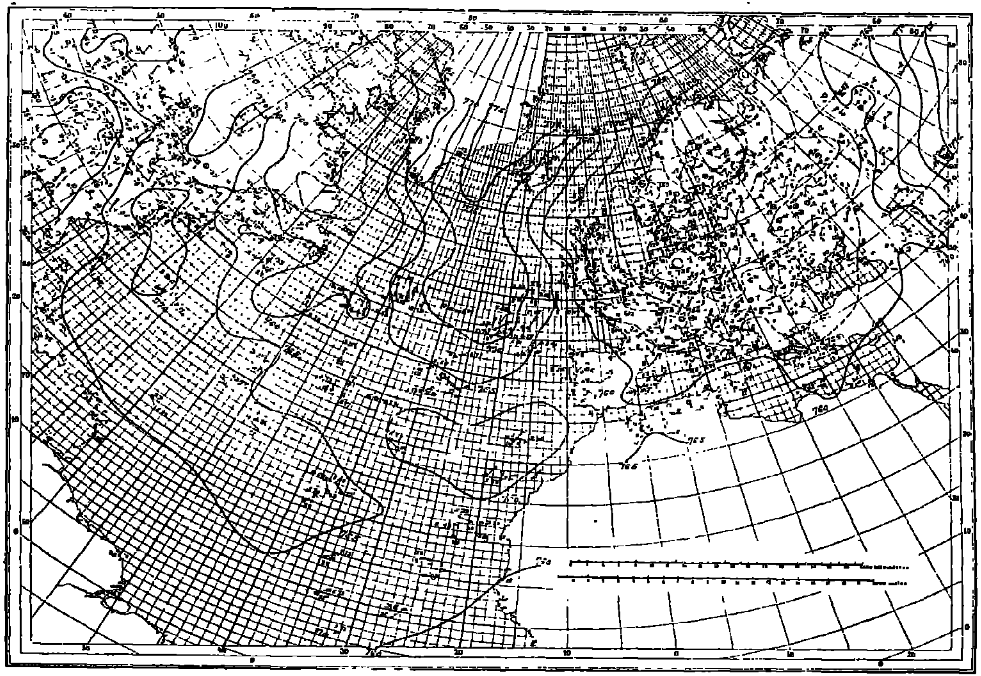


FIG 65 —Westerly Type.

FIGS. 64 and 65 —Charts illustrating the Stormy Period in the Winter of 1898—1899. (Meteorological Office.)

1895. January 25, Forenoon.

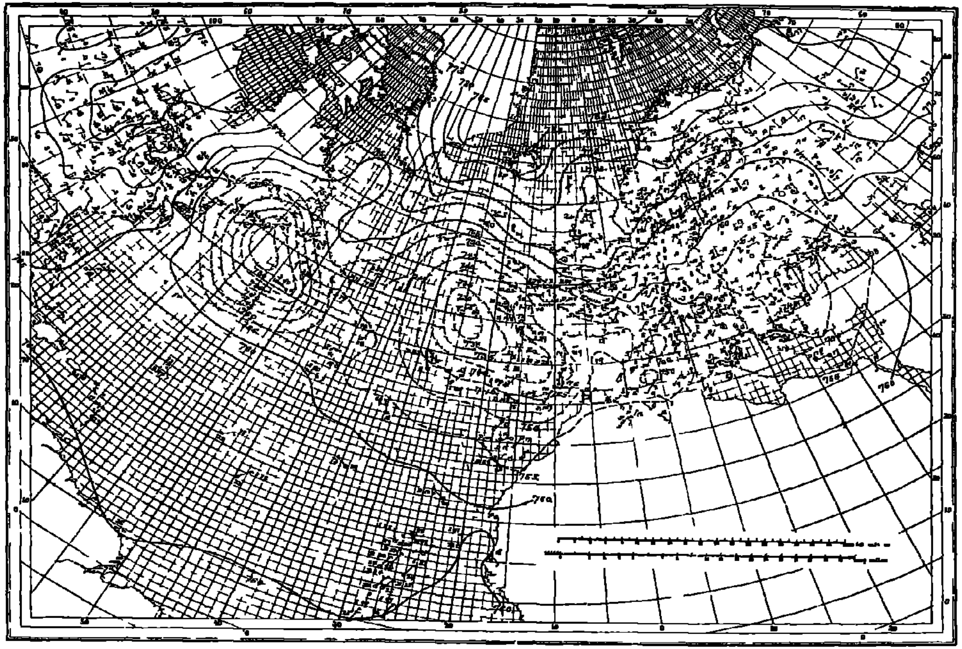


Note.

For the explanation of the symbols see p. 163 The isobars of broken line (below 760 mm.) over Britain, and the isobars of full line (760 mm. or above) over the Atlantic south of Iceland, show a general current of cold air from the extreme north with some negative temperatures (below the freezing point) in Britain.

Fig. 66.—Synchronous Chart of the North Atlantic from the "Tägliche Synoptische Wetterkarten für den Nordatlantischen Ozean," illustrating the occurrence of Northerly Winter Frost in the British Isles.

1895. February 5, Forenoon.



NOTE

The isobars of full line (760 mm or above) over Britain and the Channel, with isobars of broken line (below 760 mm) over France, and a great cyclonic area in mid Atlantic indicate the flow of a great current of air from the cold east, which produces negative temperatures (freezing weather) generally over Britain.

FIG 67 —Synchronous Chart of the North Atlantic from the "Tägliche Synoptische Wetterkarten fur den Nordatlantischen Ozean," illustrating the occurrence of Easterly Winter Frost in the British Isles

1883 March 22, Greenwich Noon.

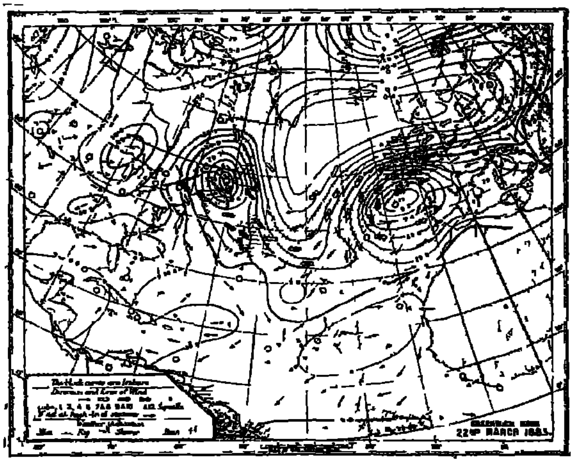


FIG 68 —North-Easterly Type The East Winds of March.
From "Synchronous Charts of the North Atlantic, August 1, 1882 to August 31, 1883" (Meteorological Office)

1882 December 28 Greenwich Noon.

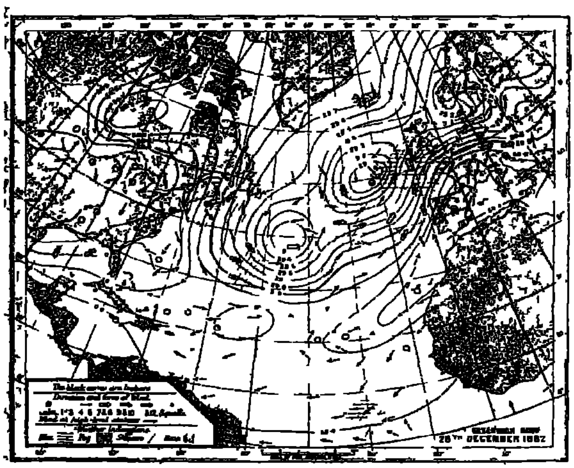


FIG 69 —South-Westerly Type Warm weather in British winter
From "Synchronous Charts of the North Atlantic, August 1, 1882, to August 31, 1883" (Meteorological Office.)

continuity between the Atlantic anticyclone and the great anticyclonic area of north-central Asia. No other main anticyclonic area is shown on our maps, but from the fact that on such occasions the barometric pressure in Iceland shows the lowest values, it is probable that further to the north and west of that island we should find a northern anticyclonic area which marks the northern boundary of the areas of low pressure.

For the easterly (north-easterly to south-easterly) type a northern anticyclonic area covers the Scandinavian peninsula, and sometimes extends along the Arctic circle to Iceland and Greenland. The British Isles are then on the southern slope of the great northern anticyclonic area, and minima of pressure are to be found between this region and the tropical anticyclone. The minima are often over the Bay of Biscay or the Mediterranean, and this low pressure region marks the separation between the tropical Atlantic anticyclone and the Asiatic anticyclone, which is now in connection with the Arctic anticyclone.

A third interesting distribution of pressure is represented by the northerly type when a high pressure area is disclosed over the North Atlantic, between the Azores and Iceland. This is sometimes persistent, as in the month of February, 1895, already referred to.

THREE-DAY FORECASTS

The study of the details of the anticyclonic areas and their movements was pursued with great assiduity by the late Professor W. van Bebber, of the Deutsche Seewarte. He founded upon that study a much more detailed classification of weather types based upon the relative positions of the characteristic anticyclonic areas. Further he introduced rules or generalisations regarding the relative permanence of the several types, and the sequence of types, so that he was able to form an anticipation of the duration of the kind of weather prevailing at the time, and the kind of weather which would

succeed it. Upon this scheme of classification, a system of forecasting for several days in advance has been based. Van Bebber's papers have not, so far as I know, been translated into English. An account of the results arrived at was given at the meeting of the British Association at Bristol, in 1898, by Mr. E. Douglas Archibald.[1] The method has been employed in the formulation of "Three-day forecasts" which appeared for some years in *The Times* and were subsequently adopted by other newspapers. From the nature of the case, the statements had to be drawn in very general terms, even more so than the usual forecast for twenty-four hours in advance, though in regard to future weather the immediate requirement of the general public is unfailing precision upon important occasions. Thus the application of the principles derived from the study of weather types is a matter of greater interest to the meteorological student conversant with the meaning of the anticipated changes than to the practical man who holds simply to the verbal description of the weather.

SPELLS OF FINE WEATHER AND THE FURTHER OUTLOOK

There are, however, conditions which one can expect to be reasonably permanent, when, in ordinary language, the weather appears to be "settled." Advantage has been taken in recent years at the Meteorological Office of our experience in this respect to issue notices of an anticipated spell of fine weather. South-westerly or westerly weather is typically "unsettled." I give on pp. 171—177 (Figs. 70A, 70B) illustrations of typically "settled" weather in 1908, from June 25 to July 3, which was the subject of successful forecasts in the hay harvest season of that year. Notifications were sent out to different parts of the country on June 23, 24 and 25. An anticyclone spread over the country. There was rain upon two days only, and then in exceptional conditions which will be referred to later.

[1] B. A Report, p 798.

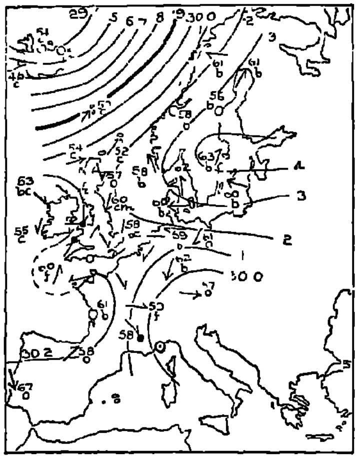
The " corridor " of fine weather across the British Isles from the permanent high pressure of the Atlantic to the polar high-pressure, which was referred to on p. 119 as characteristic of the drought of 1921, is indicated in the map for 7 h., June 21 (Fig. 71), but is much less dominant as a feature of the spell of 1908 than it is of 1921.

More recently provision has been made for giving the opinion of the forecaster, based upon his experience of weather types, as to the prospects of weather beyond the limit of the twenty-four hours by providing a column for "the further outlook," as set out in the table of p. 151. It gives him the opportunity of drawing a distinction between conditions which he knows to be transitional, and those which are, comparatively speaking, permanent.

CLASSIFICATION OF TYPES OF WEATHER CHARTS

Since the conclusion of the war the use of types of weather maps for the purpose of forecasting the weather has been systematised for the Meteorological Office by Lt.-Col. E. Gold, D.S.O., F.R.S., Assistant Director, when in charge of the Forecast Service. The method is described in " Geophysical Memoirs of the Meteorological Office," No. 16 (M.O. 220f), published in 1920. The weather maps of the area between the Mediterranean on the south-east, and Iceland on the north-west, are classified according to the distribution of high pressure and low pressure into fifteen maps, with thirteen variants represented by twenty-eight specimen charts. The 5,113 daily charts of the years 1905 to 1918 inclusive are then assigned to the respective types and then a comprehensive calendar is given which indicates on which days the particular type or variant had occurred within the fourteen years examined. That is followed by some notes on the several types relating primarily to the winds and weather of NE France and Flanders. These are of obvious service to the forecaster, but the main value of the memoir is that it gives for each type of map references to the dates upon which it has previously occurred, and therefore enables any forecaster to profit fully by the experi-

1908. June 23, 8 a.m.



Spell of Fine Weather from June 25 to July 3, 1908, Notified on June 23.

"Notifications were sent out to different parts of the country on the 23rd, 24th, and 25th of June. The subsequent weather was generally in agreement with the notification except for the overcast skies and slight rain on the 27th and 28th. That was the more remarkable and more harrowing for the forecaster, because just at that time the weather was most notably anticyclonic."

1908. June 24, 8 a.m.

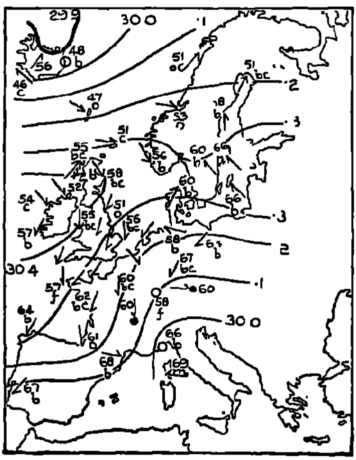
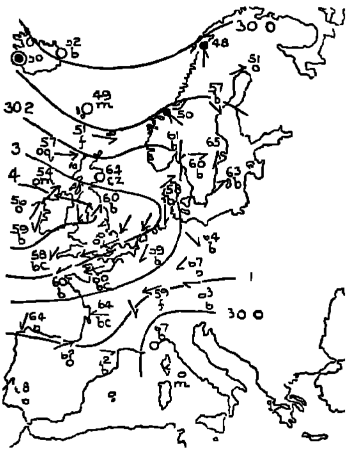
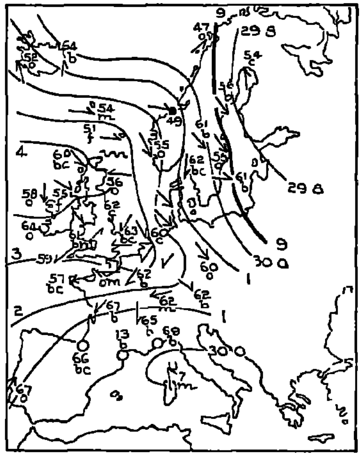


Fig. 70A.—Charts for 8 a.m. or 7 a.m., June 23 to July 3, illustrating the Hay-Harvest

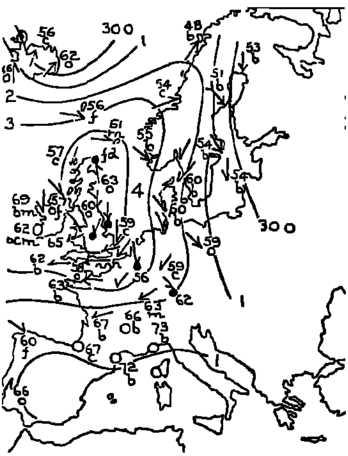
1908 June 25, 8 a m



1908. June 26, 8 a m

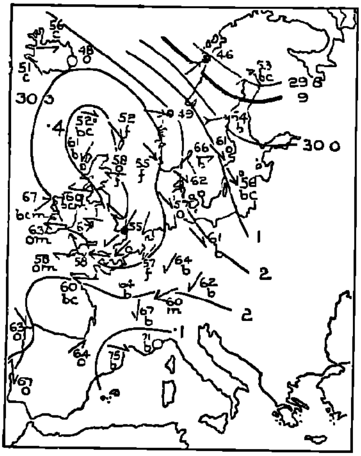


1908 June 27, 8 a m

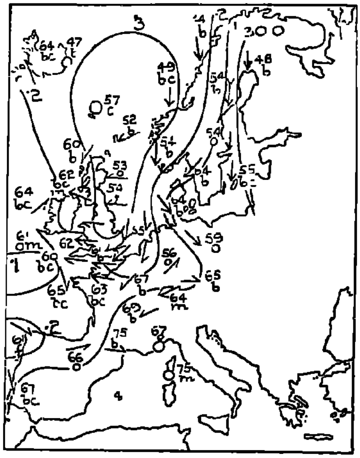


the Notifications of the Probability of a Spell of Fine Weather in Season of 1908.

1908. June 28, 8 a.m.



1908. June 29, 8 a.m.



1908. June 30, 8 a.m.

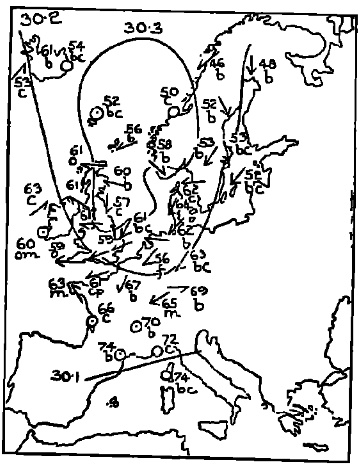
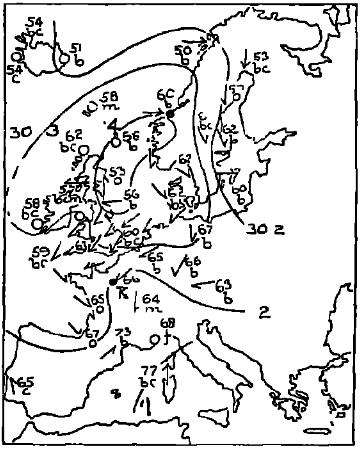
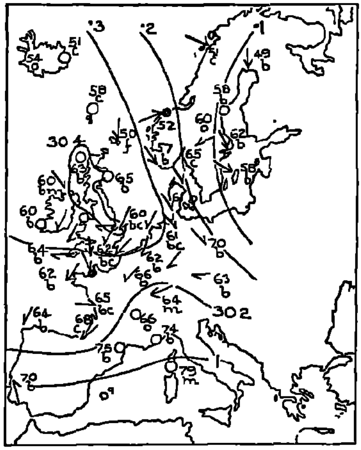


FIG. 70B.—Spell of Fine Weather (*continued*),

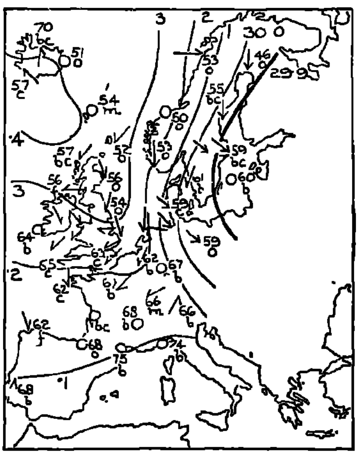
1908. July 1, 7 a.m.



1908 July 2, 7 a.m.



1908. July 3, 7 a.m.



June 28 to July 3, 1908.

1921. June 24, 7h. (8 a.m. summer time).

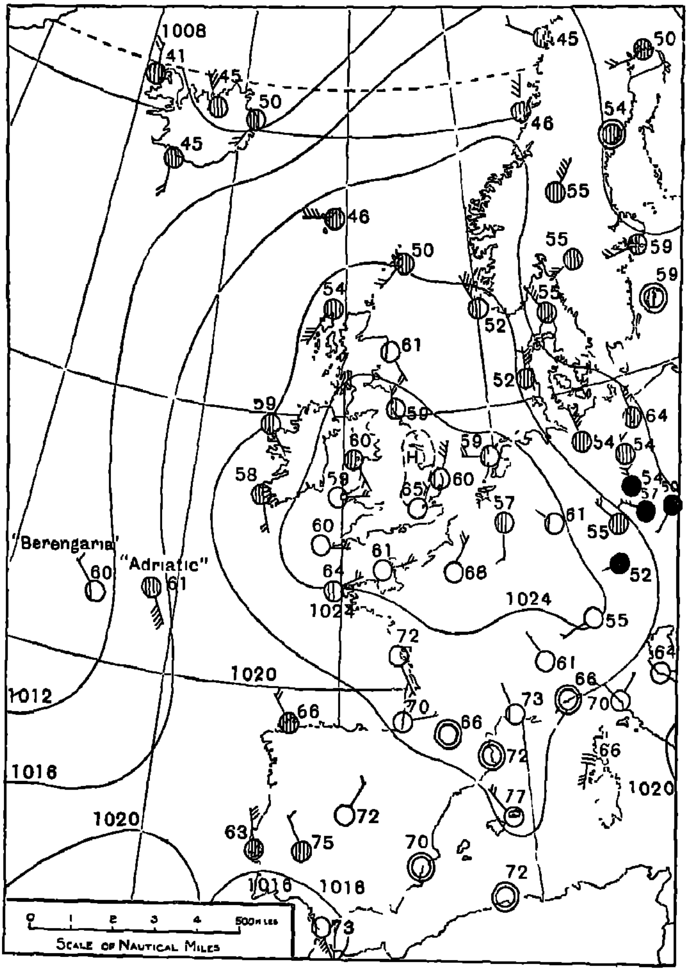


FIG. 71.—An anticyclone over England on the corridor of fine weather between the Atlantic and the Pacific, *viâ* Northern Russia, during the drought of 1921.

ence of the past by ascertaining on any occasion what happened to the weather on previous occasions most nearly similar to that with which he is concerned at the moment.

We shall attempt a brief description of the several types and variants as follows (the figures at the end of the descriptions give the number of times the types have occurred in the fourteen years) :—

Type I. High over Bay of Biscay, low over Scandinavia, gradient for NW winds over British Isles and Central Europe. (523.)

IA. Wedge of high along the English Channel between indefinite lows over the North Sea and southern France and western Mediterranean. Isobars for NW wind over Britain. N winds over Central Europe, NE winds over western France. (192.)

II. High over France, low between Iceland and Norway. Straight isobars west to east between the Channel and Shetland. (330.)

III. Similar to II., but both high and low are further south ; the low is closed by a flat oval isobar round mid-Scotland. (201.)

IV. Wedge of high pressure over Britain from high over France and Spain, with undefined lows to NE over Scandinavia and to NW south of Iceland travelling eastward. (341.)

IVA. Similar to IV., but having the high pressure less defined (less gradient) and the lows more defined (more gradient). (85.)

V. Low over Atlantic, west of Ireland, high over the Mediterranean. Isobars turning from SSW to WSW over the North Sea. (215.)

VA. Low over Iceland, high over the Italian region familiar as an example of the southerly type of p. 161. (273.)

VI. Thrust of high pressure from the eastward with ridge over the Channel. Isobars circulating from the Mediterranean over France and the British Isles to southern Norway. (155)

VIA. Parallel isobars between large high over Central and southern Europe and general low over the Atlantic. (223.)

VII. Low centred about SW Ireland, high over Central Europe. (245.)

VIIA. Low centred off the mouth of the Channel. High over the Norway Sea. (120.)

VIIB. Parallel isobars from SE to NW between low over the Atlantic and high over Scandinavia. (176.)

VIIC. Tongue of high from Scandinavia between a SW stream over Iceland and Faröe and an E stream over Europe. Somewhat similar to the situation represented in Figs. 48, 49. (146.)

VIII. The reverse of II. Parallel isobars over British Isles, low over France, high over Norway Sea. (81.)

VIIIA. The reverse of III., the isobars of type VIII. moved further south. High centred over the Shetland-Faröe channel. (84.)

VIIIB. Similar conditions, but with the high still further south centred over the England-Scotland border. (136.)

IX. Parallel isobars NE to SW over British Isles and northern and western France. (117.)

IXA. NE isobars, but low centred over NE France. High off the NW of Ireland. (87.)

IXB. The corresponding variant in the other direction. High centred over the Irish Sea, nearly straight isobars over France. (120.)

X. Nearly straight isobars N to S between high over the Atlantic and low over the middle zone of Europe. (238.)

XI. Well-formed high over the English Channel. (131.)

XIA. Col over England between highs east and west and lows north and south. The fine weather type of 1921. (291.)

XII. V-shaped depression over the North Sea extending N and S to the Mediterranean. (119.)

XIII. Group of sporadic local lows about the middle of the map within an isobar surrounding all. (60.)

XIIIA. Corresponding group of sporadic local highs. (22.)

XIV. Two marked lows arranged within an isobar from SW to NE similar to Fig. 69. (169.)

XV. Well-developed circular cyclonic depression centred on the Scottish border. (233.)

We quote on p. 182 from the table of Type-Frequencies given in

1921. September 28, 7h.

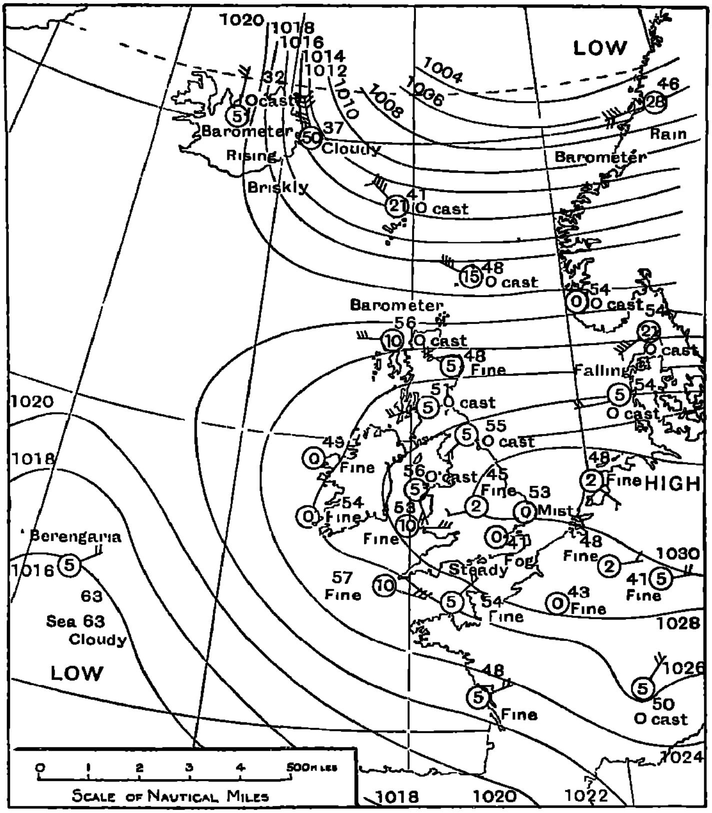


FIG. 72.—Chart upon which a forecast for fourteen days in advance was issued.

the "Memoir" the average of the number of occurrences of the several types in the several months arranged according to the yearly totals.

The introduction of this system of classification has been followed by a notable expansion of the range of the further outlook. We give the chart for September 28, 1921 (Fig. 72), upon which the further outlook for "next week" and for fourteen days quoted on p. 152 was issued. It corresponds with Type VI., to which 155 maps were referred in the fourteen years classified.

TYPES OF WEATHER-CHARTS.

AVERAGE FREQUENCY OF EACH TYPE FOR THE YEAR AND FOR THE SEVERAL MONTHS.

The total numbers of occurrences of each type in the fourteen years examined are given at the end of the descriptions of the types.

Year	Jan.	Feb.	Mar	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Type.
37·4	3·3	3·3	2·3	2·8	1·1	3·6	5·6	3·0	3·4	2·1	3·7	2·5	I.
24·4	2·2	1·5	1·6	1·4	1·5	2·1	3·0	3·6	1·7	1·4	1·7	2·7	IV.
23·6	4·9	3·1	1·9	1·3	1·0	1·3	1·4	1·1	1·7	1·4	2·1	2·4	II.
20·8	1·0	1·5	0·9	2·6	3·5	2·4	1·9	1·3	2·1	1·2	1·0	0·9	XIA.
19·5	1·1	3·4	1·6	1·6	1·4	0·9	0·6	0·9	1·1	1·6	2·4	2·9	VA.
17·5	1·1	1·0	1·9	0·9	1·7	1·4	0·8	1·4	0·8	2·6	1·5	2·4	VII.
17·0	1·1	0·8	1·4	1·7	1·5	2·1	2·1	1·6	1·9	0·6	1·2	0·9	X.
16·6	1·4	0·7	2·5	0·9	1·3	1·4	1·1	2·0	1·1	0·9	1·3	1·4	XV.
15·9	3·0	0·9	0·9	0·5	1·5	0·9	1·1	1·2	1·7	1·7	0·7	1·8	VIA.
15·4	1·8	1·9	1·6	0·6	0·0	1·1	0·9	1·6	1·1	1·6	1·6	1·6	V.
14·4	1·1	1·1	1·1	1·1	0·6	1·1	1·9	1·6	0·4	0·8	1·4	2·1	III.
13·7	0·6	0·6	1·5	1·4	1·8	1·1	2·1	1·0	1·0	1·4	0·5	0·8	IA.
12·6	1·2	0·7	1·4	0·9	1·4	1·1	0·5	0·4	1·7	1·7	1·0	0·5	VIIB.
12·1	0·3	0·6	1·2	1·8	1·0	1·5	0·9	1·0	0·5	1·4	0·6	1·6	XIV.
11·1	1·5	1·4	0·5	0·5	1·1	0·4	0·1	0·5	1·1	1·5	0·9	1·6	VI.
10·4	0·0	0·3	1·1	1·4	1·1	0·4	0·1	0·0	1·1	2·1	1·2	0·6	VIIC.
9·7	0·7	1·4	0·4	0·4	1·1	0·8	0·7	0·7	1·7	0·8	0·9	0·1	VIIIB.
9·4	0·9	0·7	1·2	0·9	0·6	0·3	0·5	1·3	1·1	0·4	0·9	0·5	XI.
8·6	0·3	0·6	1·2	0·5	0·9	0·3	0·1	0·6	0·9	1·3	1·2	0·6	VIIA.
8·6	0·8	0·1	0·6	1·6	0·6	1·4	0·6	0·9	0·8	0·2	0·4	0·5	IXB.
8·5	0·3	0·7	0·6	0·3	0·8	0·3	0·4	0·6	0·4	1·8	1·0	0·9	XII.
8·4	0·2	0·4	0·9	2·1	0·3	1·4	1·4	0·6	0·6	0·1	0·1	0·2	IX.
6·2	0·2	0·2	0·6	0·2	1·1	0·7	0·8	0·3	0·5	0·8	0·6	0·2	IXA.
6·1	0·1	0·3	0·4	0·5	0·6	0·6	0·7	0·8	0·6	0·6	0·4	0·4	IVA.
6·0	0·4	0·8	0·4	0·8	1·1	0·4	0·5	0·4	0·5	0·1	0·0	0·1	VIIIA.
5·8	0·2	0·1	0·9	0·6	1·2	0·7	0·5	0·2	0·4	0·3	0·1	0·5	VIII.
4·3	0·1	0·3	0·6	0·4	0·6	0·3	0·2	0·8	0·1	0·5	0·1	0·2	XIII.
1·6	0·1	0·0	0·1	0·1	0·2	0·2	0·4	0·3	0·0	0·1	0·1	0·1	XIIIA.

It is not, however, a complete safeguard against misapprehension of the maps. A misadventure about the position of the British Isles with respect to the warm and cold divisions of the southerly current, type IVA. or VA., brought down some wild lamentations of the daily press on January 26, 1922.

CHAPTER VII

LOCAL WEATHER IN RELATION TO WEATHER TYPES

The next subject for consideration is how far the weather assigned to a particular distribution of isobars may be regarded as generally representative of the whole district covered by the distribution, and of the whole period during which the district is under its influence—how far, in fact, the details of weather for particular localities in the same district are true to type.

It is easy to form a general idea of the local effect of orographical and topographical features upon weather—how a high level station will have more cloud and rain than a low level one, and how one on the east side of a range of mountains will get less from westerly winds than one on the west side, and *vice versâ*; how the shapes of the local ranges of hills will modify the statistics of wind direction and the estimates of wind force at inland stations. But the interpretation of all this general information into a definite reply to the question, "What will happen in this particular locality to-morrow?" is another matter. It requires a very close scrutiny of the meteorological statistics to give an answer. So far as I know, the first attempt to put into a definite statistical shape information about local weather in relation to weather types, of which we possess a vast undigested store, is represented by a paper read in 1904 before the Scottish Meteorological Society, which I am able here to reproduce. The classification into types is different from that adopted by Abercromby and described in Chapter VI., but it is really based upon the same ideas. In order to put together for statistical purposes the various days in relation to the direction of the isobars over a particular district, the cardinal points of the compass do not

give a very good means of grouping. One cannot properly include in one group a south-westerly wind and a north-westerly wind, the weather associated with the two winds is so different in character. There is an equally marked difference between a north-wester and a north-easter. It is better, if one must deal with quadrants, to group a southerly wind with a westerly wind in a south-westerly group, and stop short of going north of west, and to group a wind just north of west with a northerly wind in a north-westerly group. Thus the types here chosen are characterised by south-westerly, north-westerly, north-easterly and south-easterly winds respectively, and in order to provide for cases in which the district is under the central portion of a cyclone or anticyclone two additional types are included.

The pages next following are taken from the "Journal of the Scottish Meteorological Society":—

"It has been the practice for many years to deal with the meteorology of the British Isles in two ways, which have remained more or less distinct and dissociated. On the one hand, we have a series of daily observations at 8 a.m., 2 p.m.[1] and 6 p.m., at some twenty-five stations, reported by telegraph to London, and incorporated with similar reports from Continental stations in the Daily Weather Report. Upon these are based the maps representing the distribution of pressure, temperature, etc., which are used for the purpose of forecasting. On the other hand, there are the observations made with exemplary care and skill by some hundred volunteer observers at the normal climatological stations. They are even more full and detailed than the observations of the telegraphic reporting stations, but they differ in this respect—they are made at 9 a.m. and 9 p.m., local time, and are therefore not quite comparable with the other series in any specific meteorological inquiry, except by an expert who has the time and skill to make the necessary adjustments required by the difference of the hours of observation.

[1] Since July 1, 1908, at 7 a.m., 1 p.m.

"When this adjustment is made, the two sets of stations supplement each other in a very important manner, for the telegraphic reporting stations are nearly all on the coast, whereas the normal climatological stations, though more evenly distributed, show a preponderance of inland observations.

"To a certain extent the information, as regards rainfall, temperature and sunshine from the two sets of stations, is combined in the Weekly Weather Report, and its monthly and annual summaries; but this provides only statistical results for consecutive weeks, months or years, as the case may be. In other respects, the two sets of observations are kept distinct, and treated independently. The official publication of the daily observations of the one set takes place day by day, in a form which provides for their correlation. The publication of the other set does not take place until long after the particulars of the weather have been forgotten by the ordinary person.[1] Many of the stations are represented only by summaries for the calendar month, and the individual observations for the same days are never correlated, or only to the extent necessary to form a provisional estimate of the accuracy of the instrumental readings.

"This want of association between two closely related sides of meteorological work is a misfortune for both. On the one hand, for the purpose of the daily report and forecasts, the British Isles are divided into eleven districts, and a forecast is drawn up for each district. The forecast describes the direction and force of the wind to be anticipated, with the weather conditions incidental thereto, in the several districts; but in our country the weather conditions are partly geographical, and only partly, in the more general sense, meteorological. The extent to which geographical considerations affect the weather is a vital consideration when a description of a day's weather, limited to ten words of non-technical language, comes

[1] This also has now been changed, and publication of a month's results is completed within six weeks of the close of the month.

to be applied to the details of one-eleventh part of the British Isles.

"On the other hand, the climatological information for a single station is quite unmanageable as long as it remains in its constituent figures. It requires to be summarised before it can be usefully applied. Before it is summarised there is great advantage in referring the daily observations to the general conditions prevailing over the district in which the station is situated. Without such means of easy reference, casual errors of considerable importance are likely to remain undetected, and some of the observations which depend upon personal impression are liable to be misunderstood by the reader, and to raise more questions than they solve.

"It has been an almost universal practice to make summaries of climatological observations in the form of monthly means and extremes, and, as affording a means of describing the general conditions and as a basis for further investigation, there can be no doubt of the wisdom of this practice. The monthly maps, compiled by Dr. Buchan and reproduced in 'Bartholomew's Meteorological Atlas,' or the 'Temperature Tables of the British Isles,' published recently by the Meteorological Council, afford examples of the compendious information that can be conveyed by this system. But in relation to the actual weather of the British Isles, it suffers from a disadvantage which is obvious to all meteorologists—our weather is not organised in monthly periods, as it is in some countries; with all deference to the exponents of lunar and planetary influences, we do not, in this sense, take our weather from the moon. We have no rainy season, nor any specially dry season. We may have snow on Midsummer Day, or the weather of the Riviera on Christmas Day. Meteorologically we are in fact sometimes a part of the Eurasian Continent, the greatest land area of the globe, sometimes a part of the Atlantic Ocean, the earth's greatest natural physical laboratory. The effects of the geographical position of any station upon its weather is not of the same order under

these different conditions. A system of classification, which deals with consecutive months of weather as though they were homogeneous divisions, leaves something still to be desired for certain meteorological problems.

"The index of our meteorological relationship for the time being is not merely the time of year, but also the barometric distribution—the continental and the oceanic distributions of pressure are essentially different, and if we wish to classify our data upon a system which takes account of our exceptional meteorological conditions, we may reasonably use the barometric distribution as set out in the daily weather maps as a means of doing so. From the barometric distribution we can form some idea as to whether our meteorological conditions are, for the time being, continental or oceanic, sub-tropical or sub-polar.

"In the course of the past eighteen months, Mr. F. Gaster, who was for many years in charge of the forecast branch of the Meteorological Office, has been engaged on my behalf in making a first attempt to bring the two sets of observations at British stations, the daily telegraphic data and the normal climatological data, into relation, by using the barometric distribution as a guide to their classification, and I now lay the first results of this endeavour before the Scottish Meteorological Society. The object in view is twofold, or, indeed threefold—first, to combine the climatological data in such a way as to exhibit effectively the modifying influence of geographical position upon the general weather conditions of the locality; secondly, to work out in clear outline, and give numerical expression to, the specific character of weather associated with distributions of pressure which may be regarded as typical; and, thirdly, to secure the co-operation of the observers at the normal climatological stations, in filling in the outline and extending the work by putting together the data for their stations as they are obtained, upon some plan organised by mutual agreement.

CLASSIFICATION OF THE DATA

"The plan which I have adopted in the preliminary inquiry has been to assign each of the days of the months selected for the investigation to one or other of six types of isobaric distribution, to group together for comparison the climatological data for the several stations in a specific district (both telegraphic and climatological) for the days assigned to each type, and to express the result by taking the daily average for the days of the particular type, whether the number proved to be large or small.

"For the selection of the types, the general trend of the isobars across the district was chosen as the distinguishing characteristic. Following Buys Ballot's law, the direction of the isobars gives, with certain limitations, the direction of the wind. Six types were selected, and the days classified according to the type to which the isobaric distribution during the twenty-four hours from 8 a.m. to 8 a.m. most nearly corresponded. The types selected were as follows:—

"1. South-easterly type: a pressure distribution favourable for south-easterly winds, or, according to the amount of incurvature, for winds from east to south during the twenty-four hours.

"2. South-westerly type: for winds from south-west, or from some point between south and west.

"3. North-westerly type: for winds from the north-west, or from that to west or north.

"4. North-easterly type: for winds from the north-east, or from that to north or east.

"5. Variable Cyclonic: with the sequence of winds incidental to the passage of a cyclonic depression.

"6. Variable Anticyclonic: with the uncertain winds of the interior of an anticyclonic region.

"A specimen of each of the six types is represented in the weather charts reproduced in Figs. 73—78.

"It need hardly be said that the use of six types only does not give an exhaustive classification. I will return to this

TYPICAL WEATHER CHARTS

Illustrating Six Principal Types of Pressure Distribution.

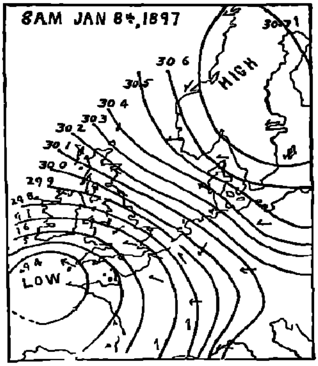


Fig. 73.—S.E. Type.

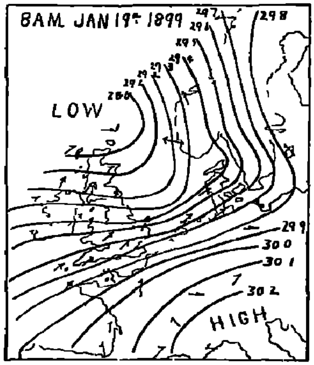


Fig. 74.—S.W. Type.

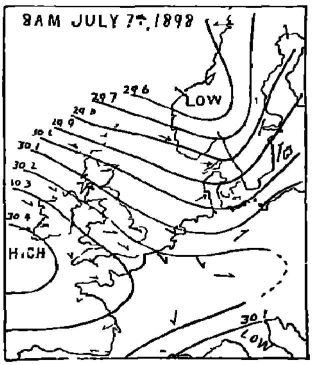


Fig. 75.—N.W. Type.

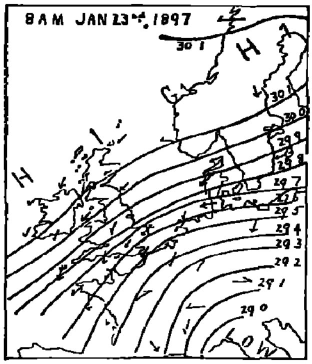


Fig. 76.—N.E. Type.

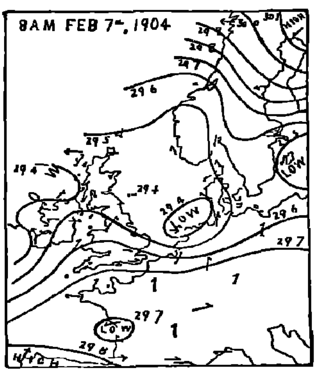


Fig. 77.—Variable Cyclonic Type.

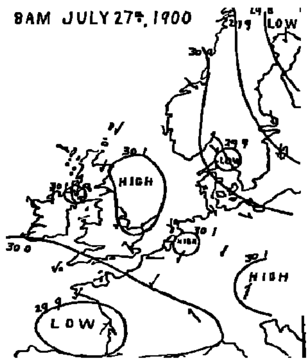


Fig. 78.—Variable Anti-cyclonic Type.

aspect of the subject later. At present it is sufficient to say that the limitation of types to six is for the purpose of simplifying the consideration of the matter in the first attempt. Similarly the classification of the winds according to the four quadrants is obviously only a first step.

"In this latter case difficulty arises because the winds from the four cardinal points have to be referred to one or other of the quadrants, and for this purpose the number of observations of wind entered as west, for example, at any one station, has simply been divided equally between the two quadrants south-west and north-west. The classification of the isobaric trend has been not quite so arbitrary, for each day has been separately considered on its merits, and assigned to the type which seemed most appropriate under the circumstances. When, therefore, the observed winds come to be compared with what may be called the ideal winds, deduced from the trend of isobars, the coarseness of the grouping of wind observations must be remembered. It must indeed be understood at the outset that if the method here described for dealing with observations commends itself to meteorologists, some understanding must be arrived at as to the extent to which it is desirable to carry classification. One of the most promising lines of study to which the results of the inquiry may be directed, is to follow out the suggestions for more effective classification that experience may indicate as desirable.

"The method of investigation has been applied to the climatological data of three of the forecast districts, 'No. 7 England NW and N Wales,' 'No. 4 Midland Counties,' and 'No. 1 Scotland E.' The technical meaning of these divisions will be clear from the map (Fig. 58) showing the districts of the British Isles and the stations which have furnished the data. Ten stations were dealt with in district 7, 'England NW,' the Isle of Man being included in the district for this occasion; eleven were selected for No. 4, 'Midland Counties' and eleven for No. 1, 'Scotland E.' So far, only the months

of January and July have been considered, and for Scotland E only January is complete. In order to obtain enough days of each type to give what might be regarded as an average result, the corresponding months of three successive years have been taken together, and thus the data for ninety-three January or July days have been distributed between the six types.

THE METEOROLOGICAL ELEMENTS TABULATED

"The following elements have been included:—

"1. Rainfall.—Expressed as the average of the amounts recorded at the station on the days assigned to each of the several types.

"2. Rain Days.—The proportion of days of each type which were 'Rain days' at the several stations, *i.e.* were days for which at least ·01 inch of rain was registered. For convenience this number is tabulated as the number of rain days experienced per ten days assigned to the type.

"3. Cloudiness.—The average percentage of covered sky at 9 a.m. and 9 p.m., or at 8 a.m. and 6 p.m. respectively, for the days assigned to each type.

"4. Maximum Temperature.—The average of the readings of the maximum thermometer for the days of the type.

"5. Minimum Temperature.—The average of the readings of the minimum thermometer for the days of the type.

"6. Sunshine.—Expressed as the average of the number of hours of sunshine recorded on the days assigned to the type.

"7. The Direction of the Wind.—For this the wind observations for the days of each type have been grouped into four quadrants; and, with the number of calms, percentages of the winds for each quadrant and of calms have been made out.

"It is evident from the principle upon which the classification has been conducted, that the south-easterly type ought to be associated with south-easterly winds at all the stations in the district, subject to two conditions:—(1) that the classification has been successful; (2) that the wind observations at the station are unaffected by local configuration or conditions.

Climatological Data.

District 7 (England, North-West), January, 1896, 1897, 1898.

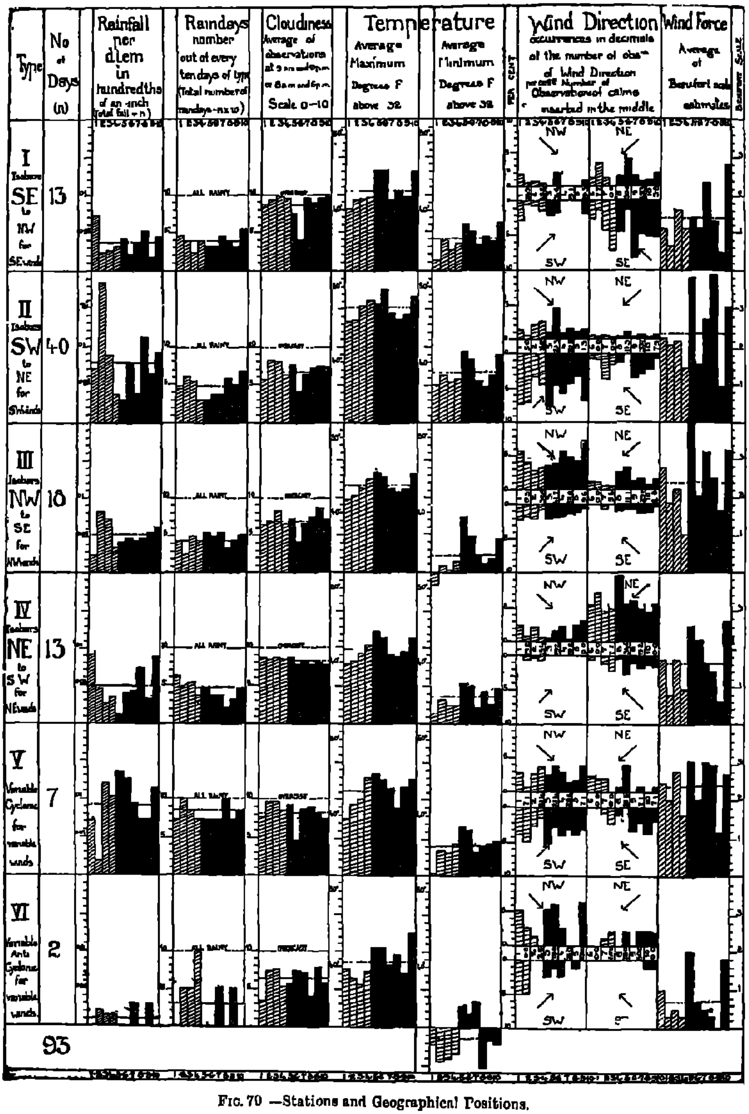


Fig. 70.—Stations and Geographical Positions.

	Lat.	Long.	Height Ft.
1. Aysgarth ...	54° 18′	1° 58′	646
2. Stonyhurst .	53° 51′	2° 28′	375
3. Prestwich ...	53° 32′	2° 17′	320
4. Chester ...	53° 12′	2° 54′	59
5. Holyhead ...	53° 18′	4° 39′	57
6. Llandudno ...	53° 21′	3° 50′	88
7. Bidston .	53° 24′	3° 4′	188
8. Heysham ..	54° 3′	2° 54′	95
9. Southport ..	53° 39′	2° 59′	7
10. Douglas ...	54° 10′	4° 29′	137

Horizontal dotted lines show the mean values for all the stations in the district.

District 7 (England, North-West), July, 1896, 1897, 1898.

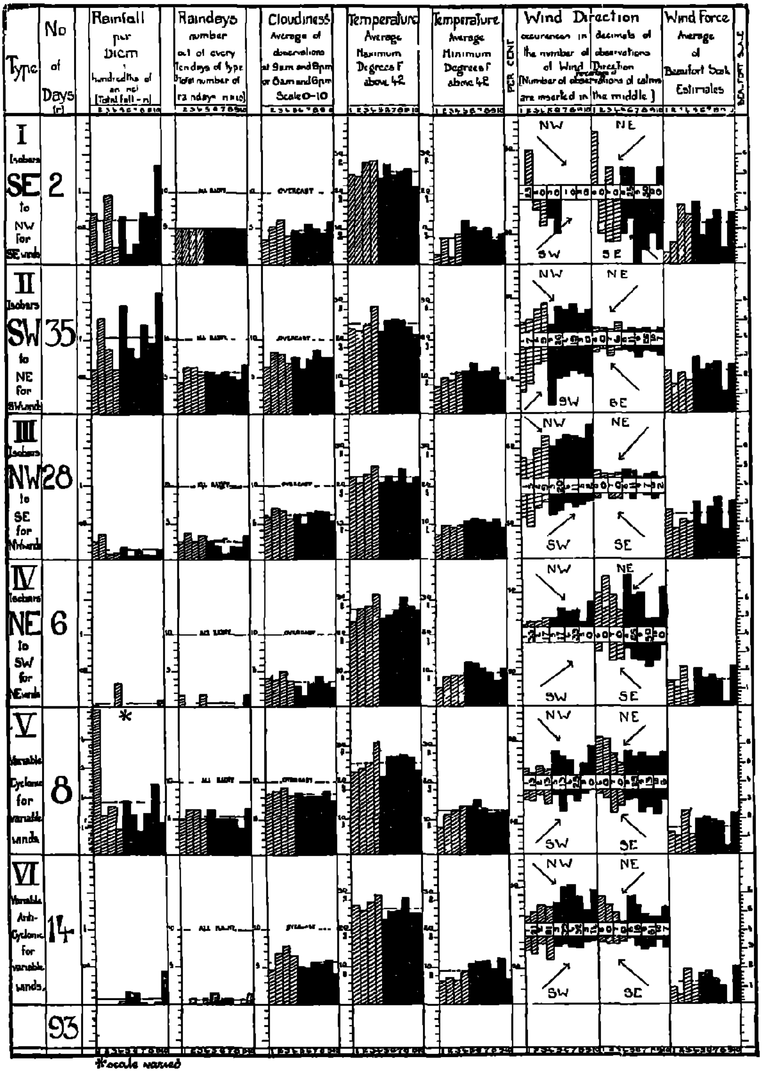


Fig. 80.—Stations and Geographical Positions.

	Lat.	Long.	Height Ft.		Lat.	Long.	Height Ft.
1. Aysgarth ..	54° 18′	1° 58′	646	6. Llandudno ...	53° 21′	3° 50′	88
2. Stonyhurst ..	53° 51′	2° 28′	375	7. Bidston ...	53° 24′	3° 4′	189
3. Prestwich ...	53° 32′	2° 17′	320	8. Heysham ..	54° 3′	2° 54′	95
4. Chester ...	53° 12′	2° 54′	59	9. Southport .	53° 39′	2° 59′	[illegible]
5. Holyhead ...	53° 18′	4° 39′	57	10. Douglas ..	54° 10′	4° 29′	137

Horizontal dotted lines show the mean values for all the stations in the district.

Hence the particulars about the wind afford an indication as to how far the wind observations at a station compare with the general meteorological conditions. It should, however, be repeated that the plan of using only quadrantal classification introduces a little uncertainty here. The days of due westerly wind will be divided between the north-west and south-west quadrants, and the former may appear as divergences from the ideal winds of the south-westerly type without very much justification. Some difficulty of this kind is unavoidable with any system of classification, but the effect is likely to be considerable when four points only are used.

"8. WIND FORCE.—The average of the Beaufort scale returns noted at the stations on the days assigned to each type has been tabulated for each station. It will be noticed that the data under this head show some unaccountable anomalies.

APPLICATION OF THE METHOD

"By this system of classification we reduce the climatological data for each station to a series of twelve numbers for each type, seventy-two in all, which can be compared one with another. The numbers for each station are thus considerable, for a group of ten stations they reach in the aggregate 720; if we add the numbers of days of the several types, we get 726 numbers, representing the data for a district which comprises ten stations.

"They can be utilised for several purposes—

"(1) To give the comparative frequency of the days of each type of pressure distribution.

"(2) To compare the results at an individual station for the various types.

"(3) To compare the general results for the districts for the several types.

"(4) To compare the stations in the same district for each type or pair of types.

REPRESENTATION OF THE RESULTS

"In order to make all these comparisons easy, it is desirable to exhibit the whole of the results on one sheet of paper in such a way as to give prominence to features that deserve attention, whether they be the general features of a group of stations or the specific features of an individual station.

"The results are shown on the diagrams Figs. 79—83. For District 7 (England NW), the specification of each type and the number of days assigned to it is given in the left-hand margin. Six hundred out of the available 660 numbers representing the data of the ten stations in the district (sunshine has not been dealt with in this diagram) are each represented by a column of suitable length, the elements for the whole set of stations being grouped in compartments. The remaining sixty numbers, representing the percentages of calms for each type and each station, are written against figures identifying the stations in the horizontal spaces crossing the columns for wind direction. The same figures at the head and foot of each column are used to identify the stations to which the individual columns refer, with the assistance of a reference list at the foot of the diagram.

"In order to distinguish between different classes of stations, the columns used to represent the data are differentiated; for example, in the first two diagrams, those for England NW (Figs. 79 and 80), the columns for coast stations are in solid black, while those for inland stations are merely hatched. In the second pair of diagrams, Midland Counties (Figs. 81 and 82), there are no coast stations, and the full black columns represent stations at a height of over 500 feet above mean sea-level, while the lower stations are represented by columns of a lighter shade. In the fifth diagram, Scotland E (Fig. 83), the black column has been retained for stations of over 500 feet, while lower inland stations have a dark shading, and coast stations a lighter shading. The averages for stations in the district are indicated in the several compartments by horizontal dotted lines.

"In each diagram the scale for each element is uniform

throughout the series of types, with the exception of the rainfall for Type 1 in Scotland E (Fig. 83), and for Type 5 in Figs. 80, 82, and 83. In these cases, which are shown by an asterisk in the diagram, the rainfall scale has had to be reduced in order to keep the diagram within reasonable dimensions. Temperatures are referred to a base line of 32° F. for the January diagrams, and to one of 12° F. for the July diagrams.

SUMMARY OF THE RESULTS

"We may now proceed to consider some of the details shown in the diagrams, and of the general inferences that may be drawn from them. First, as to the prevalence of the several types of distribution, we have the following table:—

NUMBER OF DAYS OF EACH TYPE.

Type.	England, NW. 1896—1898 January.	July.	Midland Counties. 1897—1899. January.	July	Scotland, E. 1897—1899. January.	July.
I. South-easterly . .	13	2	11	7	11	..
II. South-westerly . .	40	35	32	19	43	..
III. North-westerly . .	18	28	12	27	18	..
IV. North-easterly . .	13	6	14	13	5	..
V. Variable cyclonic .	7	8	5	6	5	..
VI. Variable anticyclonic .	2	14	19	21	11	..

"The January data for Scotland E and the Midland Counties are for the same period, and the relative preponderance of the south-westerly and north-westerly types in the more northern district represents the difference of general climatic conditions for the two districts; on the other hand, the data for the adjacent districts, England NW and Midland Counties are for periods which have two years in common, and the differences represent the differences of climatic conditions on the average of the three years.

"It is, of course, assumed here that the errors of judgment in assigning days to particular types are not sufficiently important to affect the result. This point could only be adequately decided by a re-examination of the details of the original classification, but some light is thrown upon it by a con-

sideration of the tabulated wind directions. If the winds show themselves true to type, as on the whole they do, the classification is to a certain extent confirmed.

"Some interesting points of detail may be briefly referred to.

"In the January diagram (Fig. 79), the comparison of rainfall at Aysgarth on the east of the Pennine Chain and Stonyhurst on the west shows how the rainfall is affected by the watershed. The former gets the heavier rainfall with easterly winds, the latter with westerly. The temperature columns show the advantages of coast stations as regards winter, except in the special case of Heysham, for the two days of variable anticyclonic weather in the three winters. The cloudiness column shows Llandudno in an exceptional position.

"The details of the wind-force column, particularly the lightness of the wind at Southport, clearly demonstrate the necessity for further inquiry into the methods of estimation.

"For July (Fig. 80), we may notice the remarkable inequalities of rainfall with the variable cyclonic type—the type under which thunderstorms would probably be classified (the scale of the diagram for that compartment has had to be modified to accommodate the figures), the dryness of the north-westerly and north-easterly types, the temperature relations of coast and inland stations, and again the irregularities of wind force.

"In the January diagram for the Midland Counties (Fig. 81) the results are surprisingly homogeneous, the relations of winds to type are clearly marked, and the wind forces arrange themselves in what may be called a normal manner. The conspicuous rainfall at Buxton for winds from westerly quarters is clearly brought out; and other points of interest are the dryness of the anticyclonic type, the low temperatures and abundant sunshine of the north-westerly type, with a corresponding freedom from cloud, the high temperatures of the south-westerly type, and in general the temperature relations of the different types.

"In the July diagram for the same district (Fig. 82), notice the concentration of rainfall (0·2 inch), rain-days (7), and

Climatological Data

District 4 (Midland Counties) January 1897 1898 1899

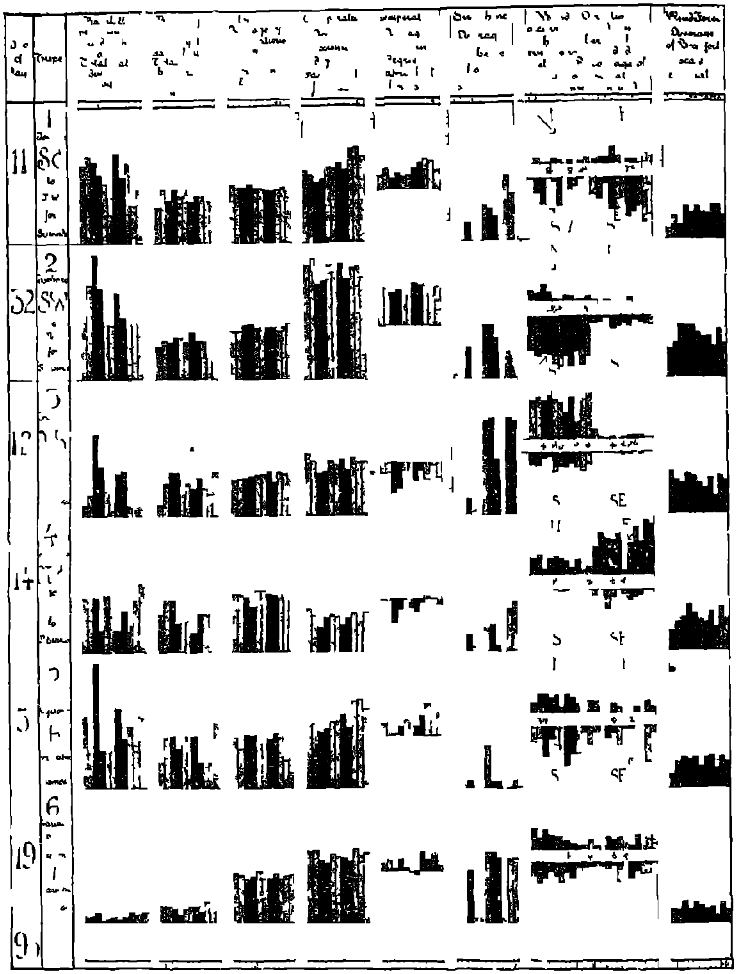


Fig 81 —Stations and Geographical Positions

		Lat.	Long	Height Ft			Lat	Long	Height Ft
1	Wakefield	53° 41	1° 30	9[illegible]	7	Churchstoke	[illegible] 31	3° [illegible]	[illegible]38
2	Sheffield	53° 23	1° [illegible]	4[illegible]	9	[illegible]	[illegible]	1°	35
3	Buxton	[illegible]° 1[illegible]	1° [illegible]	9[illegible]7	[illegible]	Cheltenham	1°	2° [illegible]	184
4	Cheadle	[illegible]	1° [illegible]	64[illegible]	10	Oxford	51° [illegible]	1° 1[illegible]	208
5	[illegible]	[illegible]	1° 1	14[illegible]	11	Berkhamstead	51° 4	0° 31	400
6	Belvoir Castle		0° 4	2[illegible]					

Horizontal dotted lines show the mean values for all the stations in the District

* An asterisk at the foot of a sunshine column indicates that there were no observations of sunshine at the corresponding station

Stations which are more than 500 ft above sea level are blacked those less than 500 ft above sea level are washed in

Climatological Data

District 4 (Midland Counties) July 1897 1898 1899

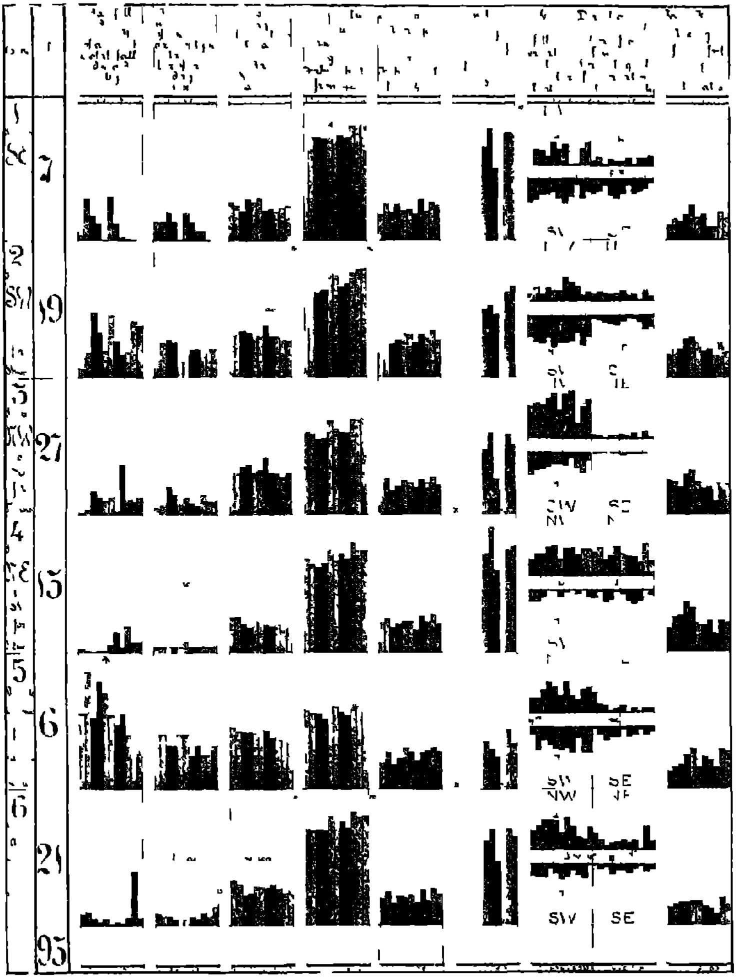


Fig 82 — Stations and Geographical Positions

	Lat	Long	Height Ft		Lat	Long	Height Ft
1. Wakefield	53° 41	1° 30'	[illegible]	7 Churchstoke	52° 31'	3° 5'	[illegible]38
2 Sheffield	53° [illegible]3	1° [illegible]	[illegible]	8 [illegible]ston	[illegible]	1° 56	535
3 Buxton	[illegible]3° 14	1° 54	98[illegible]	9 Cheltenham	51° [illegible]4	2° 3	1[illegible]4
4 Cheadle	[illegible] 5[illegible]	1° 5	6[illegible]	10 Oxford	51° 16	1° 1[illegible]	[illegible]08
5 Loughborough	[illegible]° 4	1° 12	1[illegible]	11 Berkhamsted	51° 46'	0° 34'	400
6 Belvoir Castle	[illegible]	0° 47'	[illegible]59				

Horizontal dotted lines show the mean values for all the stations in the district

* An asterisk at the foot of a sunshine column indicates that there were no observations of sunshine at the corresponding station

Stations which are more than 500 ft above sea level are blacked, those less than 500 ft above sea level are washed in.

cloudiness (8), under the variable cyclonic type, the dryness of the north-easterly and variable anticyclonic types, the high average maximum temperature (above 72°) under the south easterly type, and the low maximum (68°) under the variable cyclonic conditions, the relative irregularity of the winds, in consequence, doubtless, of the solarisation (the irregularities are most marked under the sunny types south-east and north-east).

"The diagram for Scotland E (Fig. 83) is in many respects the most interesting, not only in Edinburgh, but to meteorologists generally. Among the many points of interest a few may be mentioned:—The apparent certainty of rainfall (eight rain-days out of ten at the most favoured stations), and the abundance of rainfall under the variable cyclonic type—the scale in this type also has required modification; the irregularities of rainfall under the north-easterly type; the occurrence of substantial rainfall with winds from all quarters; the large excess of rainfall at Rosewell compared with Edinburgh for the north-easterly type; the prevalence of clouds under the south-easterly type; the high temperatures under the south-westerly type; the low temperatures under the north-westerly, and variable anticyclonic types, especially at the high-level stations Braemar and Lednathie; the absence of sunshine in the south-easterly type (not to mention the absence of sunshine data for all types).

"The irregularities in the wind force again call attention to the necessity for further inquiry into the estimates of that quantity.

"I have given, I trust, sufficient examples to show that the diagrams exhibit a number of interesting and sometimes very striking points, which would be masked or obliterated if the averages, instead of being limited to the days of the individual types, were extended over whole months. One or other of the various features would then only become apparent if the month happened to correspond with the prevalence of a particular type."

Climatological Data.

District 1 (Scotland East), January, 1897, 1898, 1899

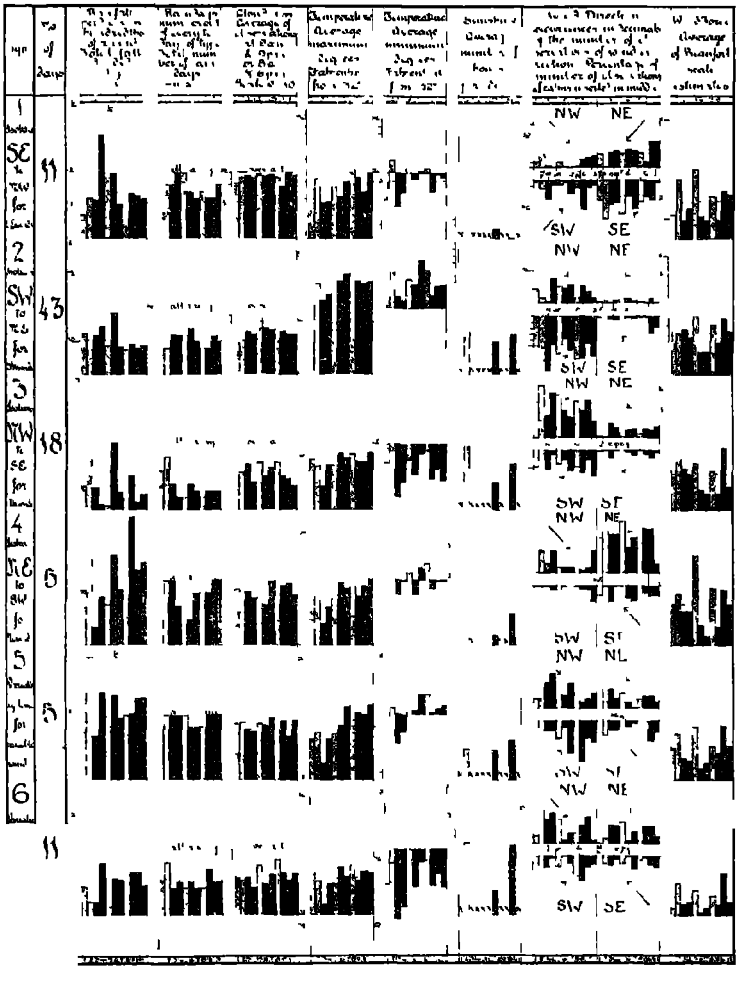


Fig. 83.—Stations and Geographical Positions

	Lat.	Long.	Height ft.
1. Nairn ...	57° 36′	3° 52′	8[illegible]
2. Old Aberdeen	57° 10′	2° [illegible]′	[illegible]
3. Braemar	57° 0′	[illegible]° 21′	1,111
4. Lednathie ...	56° 15′	3° 7′	71[illegible]
5. Dundee ..	56° 28′	2° 56′	[illegible]
6. Ochtertyre	56° 2[illegible]′	3° 53′	[illegible]
7. Edinburgh ..	55° 57′	[illegible]° 12′	[illegible]
8. Leith .	[illegible]	3° 10′	20
9. Rosewell .	55° 51′	3° 7′	690
10. Marchmont .	55° 44′	2° 2[illegible]′	498
11. Ladylaw	55° 2[illegible]′	2° 47′	447

Horizontal dotted lines show the mean values for all the stations in the district.

* An asterisk at the foot of a sunshine column indicates that there were no observations of sunshine at the corresponding station.

Stations which are more than 500 ft. above sea level are blacked; inland towns less than 500 ft. above sea-level are shaded darkly; coast towns are lightly washed in.

EXTENDED APPLICATION OF THE METHOD

After the publication of the paper from which quotation has been made, an endeavour was made to deal in the same manner with the information collected by the Meteorological Office from its telegraphic reporting stations and the stations of the second order which record observations daily at 9 a.m. and 9 p.m. local time.

The method of grouping was found too indefinite for effective classification. The items "variable cyclonic" would include the weather just north as well as just south of a cyclonic centre, and these often present most striking differences of character. Moreover, the south-westerly type would include in one category the anticyclonic side, which might be typically fine, and the cyclonic side of a great south-westerly stream of air, which might be typically rainy. It was therefore decided to divide each quadrantal group into three sections, viz., cyclonic, intermediate or straight isobars, and anticyclonic. These would still leave a few unclassified cases of cyclonic centres within the district dealt with, and a few cases of variable anticyclonic regions.

For the grouping of days at different times of the year the month was considered to be too short to give a sufficient number of cases in any one year, and the following grouping of six or seven weeks, was settled:—

January 8—February 18.—Period of greatest cold.

February 19—April 8.—Vernal equinox.

April 9—May 27.—First minimum of semi-annual variation of temperature—May chills.[1]

May 28—July 8.—Summer solstice.

July 9—August 19.—Period of greatest heat.

August 20—October 7.—Autumnal equinox.

October 8—November 25.—Second minimum of semi-annual variation of temperature—November chills.

November 26—January 7.—Winter solstice.

[1] See Shaw and Cohen, "Proc. Roy. Soc.," Vol. 69, p. 61, 1902.

The work of tabulation, begun in 1905, was done in what may be called the "spare time" of the forecast branch of the Meteorological Office. Other occupations, temporarily more pressing, have been allowed to encroach upon the spare time until the work has gradually got into arrears and ultimately come to a standstill with the year 1906 not completed. The material dealt with is already imposing as it involves the re-compilation of all the figures for twenty-seven telegraphic reporting stations, and for thirty-four stations of the second order.

I have taken out the results for 1905–6 for the normal climatological stations in all the different districts, and give some examples of the results in the table which follows (pp. 204, 205). The period chosen is the first, that of greatest cold. January 8 to February 18, and as a matter of curiosity for that period of the year I have taken the duration of sunshine. The figures show the average daily amount of sunshine at each of the stations on the days of occurrence of the several types. The number of days of each type is given for each district, and on the results of those days the stations within the districts may be compared. Where a number is enclosed in brackets the records for the corresponding station are incomplete. For a considerable number of the types the number of days is so small that no effective conclusions can be drawn from them. Perhaps the most noticeable feature of the table is the large allowance of sunshine in England east and south-east during the north-westerly types, but many more points of interest follow from an examination of the figures.

As a guide to the forecaster I have had an asterisk (*) put against the numbers of days when they were "all rainy" and a double "s" (§) when all were fair. It is to be feared that the table as a whole is in favour of "some rain in places" as a safe forecast for nearly all types in that particular period.

Local Variations of Weather in the Forecast Districts in the Period January 8 to February 18, 1905—1906.

Average Number of Hours of Sunshine per day in the Several Types of Pressure Distribution.

Type of Pressure Distribution.	S.W.			S.E.			N.W.			N.E.			Variable.	
	Cyclonic.	Inter-mediate.	Anti-cyclonic.	Cyclonic.	Inter-mediate.	Anti-cyclonic.	Cyclonic.	Inter-mediate.	Anti-cyclonic.	Cyclonic.	Inter-mediate.	Anti-cyclonic.	Cyclonic.	Anti-cyclonic.
Scotland, N. No. of days	**21**	**10**	**2**	**4**	—	—	**18**	**19**	**4**	—	—	—	**2**	—
Deerness	1·1	1·1	1·7	0·7	—	—	1·5	2·0	1·3	-	—	—	3·0	—
Strathpeffer	1·1	1·6	0·6	(0·2)	—	—	1·7	1·9	1·2	—	—	—	6·7	—
Scotland, W. (with Cumberland and I. of Man.) No. of days	**18**	**12**	**5**	**1***	**2**	**1§**	**9**	**21**	**6**	—	—	**2**	**3**	**2**
Glasgow	1·1	1·0	1·9	—	—	—	1·2	2·9	1·1	—	—	3·4	2·7	(0·0)
Aspatria	1·0	2·1	2·3	1·1	3·1	6·2	1·5	2·6	1·6	—	—	3·9	1·4	2·7
Douglas	1·2	1·3	3·2	0·0	0·1	0·0	3·0	3·4	1·9	—	—	5·0	2·8	3·3
England, N.E. No. of days	**19**	**10**	**3**	**2**	—	**4**	**8**	**18**	**9**	—	**2**	—	**2**	**5§**
Morpeth	2·0	1·1	0·8	(0·4)	—	0·0	3·6	3·8	3·8	—	2·4	—	2·9	4·7
Newcastle	1·2	0·0	—	1·5	—	0·0	1·6	2·3	2·5	—	1·2	—	2·3	1·4
Durham	1·9	0·6	1·0	3·2	—	0·2	2·9	3·2	3·3	—	1·2	—	1·5	4·2
York	1·0	0·8	0·0	2·8	—	0·1	1·6	2·6	3·5	—	1·1	—	0·2	3·0
England, E. No. of days	**10**	**13**	**3**	**1***	**1**	**3**	**4**	**24**	**9**	—	**2**	**1**	**3**	**8**
Cromer	1·7	2·6	0·6	0·3	1·9	3·6	3·9	3·4	4·4	—	1·1	1·2	(1·2)	3·6
Geldeston	1·7	2·6	0·3	0·2	0·6	4·4	4·3	3·6	4·1	—	1·0	0·5	(0·4)	3·2
Cambridge	1·2	2·1	0·3	3·2	4·3	3·1	4·0	3·8	4·9	—	1·4	1·5	0·0	3·3
Dunmow	0·9	2·1	1·0	1·7	2·8	3·0	4·0	3·4	4·5	—	2·4	1·0	0·2	2·6

ENGLAND, S.E. No. of days	**8**	**11**	**3**	**1***	**2**	**3§**	**5**	**17**	**15**	—	**2**	**2**	**6**	**7**
Southampton	1·2	2·4	0·4	0·0	1·9	1·9	5·1	2·9	4·3	—	5·1	4·6	(0·5)	3·1
St. Leonards	1·9	2·8	0·0	0·0	4·8	2·4	3·6	3·6	5·3	—	5·7	2·6	0·4	4·3
Eastbourne	2·0	2·5	0·3	0·0	3·2	2·3	3·4	3·1	4·8	—	1·8	3·1	0·3	4·1
Ventnor	1·3	2·1	1·0	0·0	2·1	2·0	4·2	2·8	4·9	—	5·7	5·5	2·2	4·6
MIDLAND COUNTIES. No. of days	**7***	**13**	**3**	**1***	**1§**	**3§**	**4**	**22**	**12**	—	**2**	**1§**	**5**	**8§**
Birmingham	1·5	1·3	0·3	0·0	0·0	0·7	2·3	2·5	2·7	—	2·9	0·0	0·8	2·2
Sheffield	2·2	1·8	1·4	2·2	0·0	0·5	3·0	2·2	3·6	—	1·3	2·2	1·1	2·3
ENGLAND, N.W. No. of days	**9**	**10**	**9**	**1***	**2§**	**3**	**6**	**18**	**13**	—	—	**2**	**5**	**4**
Newton Rigg	1·6	0·6	2·0	4·2	0·6	1·6	2·1	2·4	2·1	—	—	3·4	3·5	3·8
Stonyhurst	0·6	0·8	1·6	0·4	0·7	0·1	1·8	2·2	2·0	—	—	3·2	2·7	4·4
Manchester	1·1	0·3	1·3	0·7	1·2	0·0	1·8	1·7	1·1	—	—	3·0	(1·1)	1·8
Llandudno	2·1	1·7	1·7	0·0	2·1	1·8	2·2	1·7	2·6	—	—	1·7	2·9	4·6
Bettws-y-Coed	1·4	0·7	0·9	1·1	1·6	0·8	0·8	1·5	1·7	—	—	2·0	2·1	3·7
ENGLAND, S.W. No. of days	**4***	**12**	**10**	**1***	**4§**	**4**	**3***	**12**	**17**	**1***	**1***	**3§**	**5**	**8**
Plymouth	1·9	1·6	1·4	0·0	1·8	1·7	2·5	2·6	4·2	0·0	5·8	5·6	1·1	4·0
IRELAND, N. No. of days	**13**	**15**	**13**	**2***	**4**	**1§**	**5***	**20**	**17**	—	—	**2§**	**2**	—
Markree	1·1	1·1	1·5	0·0	1·8	0·0	2·6	2·0	2·1	—	—	3·2	5·4	—
Armagh	1·1	1·5	1·6	0·0	0·1	0·0	2·5	2·6	2·2	—	—	2·3	3·8	—
IRELAND, S. No. of days	**5**	**12***	**22**	**2**	**4§**	**1§**	**4***	**10**	**13**	—	—	**2§**	**2***	**6**
Dublin	2·0	3·0	2·3	0·4	1·9	2·0	3·3	3·6	2·9	—	—	2·6	3·5	1·9
CHANNEL ISLANDS. No. of days	**6***	**10**	**6**	**1***	**2**	**3§**	**5***	**18**	**15**	—	**1§**	**3§**	**6**	**7**
Guernsey	1·0	2·7	2·4	0·0	0·7	1·6	2·5	2·7	4·6	—	2·8	5·4	1·6	4·2

* All rainy. § All rainless.

CHAPTER VIII

THE PHYSICAL PROCESSES OF WEATHER

As a further necessary preliminary to an endeavour to give a dynamical or physical explanation of the recognised principles of forecasting by means of synoptic charts, we now proceed to consider the physical processes which may, or, in a sense, must be involved in the sequence of phenomena included in the term "weather." We have dealt with the relation between wind and pressure in Chapter IV. We may here recapitulate in a few sentences our position with regard to that part of the subject. The only forces which, so far as we know, are available to produce horizontal motion in air are the forces due to the distribution of pressure. It is perhaps not unnatural for a reader who has paid little attention to the actual conditions of the atmosphere to regard still air, or calm, as a normal condition, and wind, or moving air in the manifold forms described in Chapter V., as a disturbance of the normal state. Further consideration, however, leads us to consider a steady current in which the barometric pressure-gradient is balanced by the velocity of the air as being the only reasonable representation of normal atmospheric conditions, and the production and maintenance of a calm as being something of the nature of a meteorological curiosity. If we imagine for a moment an originally calm atmosphere, the variations in temperature due to the unequal heating of different parts will give rise to differences of pressure, and differences of pressure will set the air in motion, initially, down the gradient. The rotation of the earth at once operates to cause a deviation, and the motion soon adjusts itself so that the gradient is balanced by the velocity. We find when we consider the air at some distance above the surface that the balance between gradient and velocity is very

closely kept in many parts of the world, and many of the most obvious phenomena connected with the distribution of pressure and wind are explained on the supposition that such a balance exists. It is reasonable therefore to regard the normal state of the atmosphere as a steady state of circulation in which gradient is balanced by velocity disturbed by surface friction and other causes. This method of regarding the normal state is the more reasonable because it gives us a normal which actually corresponds with the average state as derived from the combination of observations the world over and is represented in its main outlines by the isobaric lines of the charts of average pressure, whereas an imaginary normal state of calm corresponds with nothing that, speaking generally, can be regarded as an average result for any part of the earth's surface. We shall therefore endeavour as far as possible to keep in view the idea that the physical processes which we are considering take place in some modification of a steady state of circulation, and not in a quiescent atmosphere.

This idea is really essential to a proper understanding of the dynamical conditions, and hence of the stability or instability of the meteorological situation represented by synoptic charts. It suggests that the great streams of air, sometimes as much as 1,000 miles broad, are, from their own momentum, features of greater importance from the dynamical point of view than the positions of high or low pressure. The impression to be gathered from current meteorological literature is that the meteorological situation is represented by the meandering of high and low pressure areas in an inert medium, the undisturbed air. We are accustomed to speak of a cyclone encroaching upon an anticyclone, or an anticyclone resisting the advance of cyclonic depressions, as though there were a neutral field of operations in which these encounters take place. As a metaphorical description of a sequence of meteorological conditions, this particular form of literature has its utility, but the limits of utility are very easily passed. The cyclone, the anticyclone, and the areas in which they operate are all parts

of a single general circulation of currents. An anticyclone is maintained by the currents which circulate round it. If they fail the high pressure disappears, and similarly it is not possible often to say whether a centre of low pressure is the cause or the consequence of a westerly current of wind.

CHANGES OF TEMPERATURE

It is important to recognise at the outset that the temperature of moving air may change for either of two fundamental reasons—(1) because it takes up heat from other hotter bodies or gives out heat to other colder bodies, or (2) without any transference of heat whatever, and simply on account of the alteration of its pressure. It is doubtless difficult to find cases in nature in illustration of one of these causes of change of temperature without complication by the other; but in the laboratory it is quite easy to show experiments in illustration of either separately, and it is not at all difficult to find examples of natural processes in which the one cause or the other is clearly predominant.

Air is warmed by taking in heat when it passes over warmer ground, or warmer water, and conversely it is cooled when it passes over colder ground or colder water. In "The Life History of Surface Air Currents" it is noted that, as a result of the operation of this exchange of heat between the air and the land or water, it may be said that over the sea the temperature is controlled by the water, whereas on land the control of temperature is with the air. But the ground is the first to show the effect of heating in the sun's rays by day or cooling under a clear sky by night.

SOLAR RADIATION

The thermal processes of heating and cooling of the atmosphere begin originally with the transmission of energy in the form of wave motion by radiation from the sun. The solar radiation includes waves of a great diversity of wave-length from the invisible radiation of long wave-length beyond the

red end of the spectrum to the invisible radiation of short wave-length beyond the violet of the spectrum. The whole of the energy of this radiation would be represented by its equivalent in heat if the rays fell upon a perfect absorber. Lamp-black is practically a perfect absorber or a perfectly "black" body for all rays. Part of the solar energy of radiation is absorbed by the gaseous constituents of the atmosphere, part by the dust in the atmosphere, so that the air is warmed directly by the absorption of solar energy, and, *per contra*, it is cooled at night by the radiation from the gaseous constituents and the dust particles to the clear sky. Of the gaseous constituents water-vapour is the chief radiator and absorber of radiation of long wave-length.

Regarding the particular side of the subject that deals with the disposal of the radiant energy of the sun when it reaches our atmosphere, the processes are very complicated. Part of the energy is dispersed and the dispersal is held to account for the blueness of the sky; part is absorbed selectively by the gases and vapours of the atmosphere, that is to say the energy represented by waves of different length, or by light of different colour, to use the phraseology of optics, is subject to different degrees of absorption by the various constituents of the atmosphere. Part is reflected from the upper surface of clouds or of the sea or earth, and traverses the atmosphere again. Some is reflected and some absorbed by the dust that floats in the atmosphere and the remainder is absorbed by the sea water or the objects on the earth's surface upon which the radiation falls.[1]

Hence to give a detailed account of the distribution of the solar energy which reaches the atmosphere is beyond our power. What is observed as a meteorological element by the standard instrument for measuring solar radiation known as

[1] Estimates of the ultimate distribution of radiation are given by Mr. W. H. Dines in a paper on "The Heat Balance of the Atmosphere" in the "Q. J. Roy. Met. Soc.," 1917, and other particulars about radiation in relation to the atmosphere are given in "Atmospheric and Terrestrial Radiation," "Q. J. Roy. Met. Soc.," vol. 46, 1920, p. 163; and in "Geophysical Memoirs," No. 18 (M.O. 220h), "Observations on Radiation from the Sky."

a pyrheliometer or bolometer is the total amount of solar energy absorbed by a blackened strip or wire of platinum exposed to the sun's rays. From this may be computed the amount of energy supplied by the sun to a measured area, but reduced by the losses incidental to the passage through the atmosphere. For many years the temperature of a black bulb *in vacuo* has been read as an index of the intensity of solar radiation, but no means have been found for interpreting its readings in terms of the energy received upon a measured area.

Interest in measurements of this character has been quickened by the work of Mr. H. H. Clayton, formerly of Blue Hill Observatory and now attached to the Meteorological Office of Argentina. He finds a direct connection between measurements of solar radiation in the Andes (Calama, Chile) and the subsequent temperatures at Buenos Aires. We shall refer to the matter again in Chapter XXIII.

In our study of dynamical meteorology we can only deal with the indirect effects which the absorption of solar radiation produces, and which are represented by the changes of temperature of the sea and of the land surface, and thence. indirectly, of the surface layers of air. We may suppose that this communication of heat to the surface layers of air is the chief source of heat for the atmosphere.

CONVECTION OF HEAT

When air absorbs heat by contact with the ground or directly from the sun its temperature rises, provided, as we shall see later, that its pressure is not automatically diminished. It becomes therefore specifically lighter, and if the heating is localised the lighter air will be pushed upward by the descent of the surrounding air. It must be remembered that for heated air to ascend there must be cooler air to take its place; it must not therefore be assumed that every place where air is warmed is necessarily a place where air is ascending. Generally speaking, however, localities where air is being warmed by the sun are localities where air is rising.

This process tends to limit the extent to which the surface air can be heated, in other words it fixes a superior limit to the reading of a maximum thermometer. On the contrary, surface air which is cooled locally must remain on the surface or trickle down to lower levels like water. The limiting readings of minimum thermometers are therefore much less restricted than those of the maximum, and it will be noticed that readings of the maximum thermometer at different stations on a hot day show much less variation than the readings of the minimum thermometer on a cold night.

CHANGES OF TEMPERATURE WITHOUT COMMUNICATION OF HEAT—DYNAMICAL COOLING

Hitherto we have considered the changes of temperature that are associated with the communication or abstraction of heat; let us now turn our attention to the method of altering the temperature of air without transference of heat. From the numerical point of view the question is closely concerned with the principle of the conservation of energy. For a certain amount of work measured in foot-pounds, gramme-centimetres, or ergs, a certain equivalent in heat, measured in pound-Fahrenheit units, or in gramme-calories, can always be obtained. When air is compressed in a closed space, as, for example, by pushing a piston into a cylinder, the compression represents a certain amount of work. This work is just as effective in warming the gas as if it had been first converted into heat and then the heat transferred to the gas. The constitution of the gases that compose dry atmospheric air is such that practically all the work of compression is disposed of in this way, and the amount of dynamical warming due to compression can be calculated. Here are the formulæ:—Suppose that the volume of a quantity of dry gas is changed by compression from v_0 to v, and the temperature measured from "absolute" zero is changed in consequence by dynamical process from T_0 to T, then

$$\log T - \log T_0 = \cdot 41 (\log v_0 - \log v).$$

Suppose that we know the alteration of pressure; for that case we have the formula:

$$\log T - \log T_0 = \cdot 29\,(\log p - \log p_0).$$

If we wish to demonstrate this effect practically we must take steps to prevent it being masked by the loss of heat which will begin to take place as soon as a difference of temperature has been produced by dynamical process. One way of doing this is to produce the compression suddenly so that there is not time for the heat to escape. A better way would be to have the air in a vessel made of material that is perfectly impervious to heat, only, unfortunately, no such material exists. Consequently experiments in this subject require skill and attention. Rapidity of compression is needed, and, as far as possible, heat insulation also. Many experiments in illustration of dynamical heating are described in Tyndall's "Heat a Mode of Motion," and they generally find a place in a course of physics. The process is perfectly reciprocal; expansion without communication of heat will produce cooling just as compression will produce heating. The same formulæ are applicable.

The process and the corresponding formulæ are fundamental for dynamical meteorology, because in the atmosphere the elevation of air necessarily implies a reduction of pressure and descent of air corresponding increase of pressure. Elevation or descent may take place comparatively quickly and in circumstances such that there is practically no means of adding or taking away heat from the ascending or descending air. For example, suppose a mass of air becomes warmer at the surface and rises; after it leaves the surface no further communication of heat can take place except what can be got from radiation, either solar or terrestrial, passing through it, or from the juxtaposition of masses of different temperature. For the interior portions of the mass of air the latter can have no effect, and the effect of radiation upon transparent air is very small. Hence what may be called a floating cloud of transparent air is practically entirely protected from the

communication of heat by conduction or radiation, and must respond almost completely to the changes of temperature depending upon dynamical changes, that is, in this case, to changes in pressure alone.

When a mass of air is so protected that no heat can be transferred to it or taken from it by conduction or radiation while it is exposed to variations of pressure, the conditions are said to be *adiabatic* or *isentropic*, the first term indicating that there is no transference of heat, and the second that there is no change of *entropy*. Since entropy can only be changed by adding or taking away heat, the two terms indicate the same conditions, but the term "adiabatic," meaning that there is no flow of heat through the boundary, has reference to the external conditions, while the term "isentropic," meaning that the entropy of the gas remains the same, has reference to the gas within the supposed enclosure. However, for all the purposes with which we are concerned, the two may be regarded as expressing the same idea, namely, the restriction of the changes to those produced dynamically without any communication or loss of heat as heat.

COOLING BY WARMING

The conditions of the atmosphere under which adiabatic changes take place lead to the paradoxical result that the communication of heat to air may be the cause of its becoming colder, that is, of its temperature being reduced. The condition may be understood as follows:—Suppose we have a quiet atmosphere, and that a part of the surface layer is warmed by contact, for example, with warm earth. The warmed air will rise; how far it will rise depends upon how far it has to go in order to find air of its own temperature. The ascending air will cool to begin with at the rate of 1° F. for 185 feet The surrounding air is also cooler as we go aloft, If its rate of lapse of temperature, as it is called, is as much as 1° F. for 185 feet, the adiabatic lapse-rate for dry air, the ascending air will find no resting place; in every position it will be

warmer than the surrounding air, because it started warmer, and the two cool equally: it will thus always go on rising and consequently cooling. Hence, if we had an atmosphere with the temperature lapse-rate, from bottom to top, of 1° F. for 185 feet, the warming of a part of the bottom layer by a single degree would result in its rising to an unlimited height with consequent unlimited reduction of temperature.

It is seldom, however, that the lapse-rate of temperature in the surrounding air is as much as the adiabatic lapse of 1° F. for 185 feet. It is usually about 1° F. for every 300 feet. In that case the rising air will lose 1·6° F. in 300 feet, whereas the surrounding air will be only 1° lower. Hence the rising air will lose ·6° F. for every 300 feet as compared with the surrounding air. So if it starts with 2° of difference, the temperatures will be equal at 1,000 feet, but the temperatures of both will be 3·3° F. below that of the surrounding air at the surface. Hence, we have the paradoxical result that the effect of warming a portion of surface air by 2° is to reduce its temperature by 3° on balance, by lifting it to 1,000 feet. In other words the result of warming it by the communication of heat enough to raise its temperature *in situ* two degrees, is in the end to cool it three degrees.

This paradoxical effect may be illustrated experimentally by an apparatus which was exhibited at a conversazione of the Institution of Civil Engineers, and subsequently at the British Association at Southport, in 1903, and which received the name of the "thermopsych" because it demonstrates the cooling of a mass of air by communicating heat to it. An earlier form of the apparatus is shown in a paper on "La Lune mange les Nuages," read before the Royal Meteorological Society in 1902. The representation of the more recent form is given in the reprint of the paper at the end of this chapter Fig. 93.

It is a matter of some consequence in dynamical meteorology to realise the importance of those changes of temperature due simply to changes of pressure. They are

generally referred to as phenomena associated with dynamical cooling or dynamical heating. The modification in the equations which is introduced when water vapour is contained in the air will be dealt with later on.

HUMIDITY

Water vapour is the most variable of the constituents of the atmosphere. The supply is replenished in an invisible manner by the silent evaporation of water or ice from the surface of sea and land, and particularly from trees in leaf. Evaporation is always taking place so long as the air in contact with the surface is not completely saturated. The restoration of the water to the surface is not by any means so unperceived or undemonstrative. Rain, snow, hail, and all their consequences are incidents in the process of restoration of the evaporated water to the earth's surface again.

The amount of water held in suspension in the atmosphere at any time is only a small fraction of that which takes part in the atmospheric circulation in the course of a year. An inch of rain would as a rule be more than enough to represent the amount of water contained in a vertical column of atmosphere if it were saturated, so that for heavy rainfalls it is in a peculiar sense that the air can be regarded as the carrier of the moisture. It must not be supposed that a cloud can be charged with water-drops to such an extent that, by carrying them over the country and dropping them gradually, as if from a watering-can, it can supply the rain that is actually measured at the surface. The cloud must be regarded rather as marking the position at which rain-drops are being formed by the continuous ascent of fresh supplies of air.

The physical conditions by which the evaporation and condensation of water in the atmosphere are regulated are not easily grasped without a course of experiments in illustration of the properties of mixed gases and vapours, and such a

course cannot find a place in this work. I shall, however, attempt a resume of the results for the sake of keeping certain definite ideas in mind.

First of all let me say a word or two about dry air.

I must begin by saying that the term "dry air" is used by different persons or on different occasions in two different senses, and it is not unlikely that this practice may lead to some confusion unless the reader is on his guard. For the student of physics, "dry air" means air from which all water vapour has been completely removed. To whatever extent it may be cooled by artificial or natural means, no "dew-point" could ever be reached, that is to say, no deposit of water could be obtained from it. For the ordinary person and for the meteorologist the air is dry when it has considerable capacity for absorbing water vapour by evaporation from wet surfaces. One can make comparisons and call one sample of air dry and another very dry, according to their power of evaporating water, and. indeed, meteorologists speak of degrees of dryness as the counterpart of degrees of humidity. For the student of physics there are no degrees of comparison as regards dry air. It is either dry because it contains no water vapour at all, or it is moist, not in the trivial sense of causing a deposit of water on walls, buildings, or clothing, but in the sense of holding some water-vapour which can be made evident as a deposit upon a polished surface by sufficient cooling.

I am afraid that it would be necessary to coin a new word if I wished to keep separate the two senses of the word dry, and I will not attempt that. With practice, the context gives a sufficient indication of the sense that is intended.

All air, as we find it, is more or less moist, and the dry air of the student of physics is an artificial product obtained by removing all the water vapour. The ordinary way of doing this is to pass the air over substances which absorb water vapour. Strong sulphuric acid or phosphoric anhydride is the best; calcium chloride is nearly as good, but it is not so

effective as the others. A better way of drying air on the commercial scale is to reduce its temperature. Very little water vapour is left if the temperature is reduced below the freezing point, and reduction to a temperature near the point of liquefaction of air renders it perfectly dry for all practical purposes by condensing the water vapour.

The next idea which should be formulated is that of the saturation of air by water vapour. More strictly, perhaps, we ought to speak of the saturation of a space by water vapour because in a closed space, with a supply of water in it, the amount of water vapour will be the same whether there is dry air or any other gas present or not. The statement of this important principle is known as Dalton's law.

Let us suppose that we have a closed vessel which contains dry air, of which we have some means of measuring the pressure. Let a few drops of water be introduced into the vessel, and watch the pressure gauge to see the effect of introducing the water. As water evaporates, the pressure in the closed vessel will increase by the addition of the pressure of the water vapour formed, until a certain limit is reached which depends upon the temperature of the vessel and, curiously enough, upon nothing but the temperature. Hence, if we wish to make the experiment, it will be necessary to take precautions to keep the temperature constant, or to know its variations. The original pressure of the dry air may have been anything whatever—an "atmosphere,"[1] or 1,000 millibars, one-tenth of an "atmosphere," or 100 millibars, or none at all; the evaporation will go on, always supposing that the temperature is kept the same, until the pressure has been increased by a certain fraction of an "atmosphere" depending upon the temperature. At 32° F. the increase of pressure due to water vapour will be $\frac{1}{160}$th of an "atmosphere," at 50° F. twice as much, *viz.*, $\frac{1}{80}$th of an "atmosphere," at 78° F.

[1] An "atmosphere" is used here to signify the pressure of a megadyne per square centimetre or the average atmospheric pressure at 106 metres above sea level, approximately equivalent to 29·5 inches, or 750 mm.

$\frac{1}{31}$st, at 96 F. $\frac{1}{17}$th, at 114° F. about $\frac{1}{12}$th, and at 211·3° F. a full "atmosphere" in the sense in which we are using the word here. These pressures are the saturation pressures of the water-vapour at the respective temperatures, and when expressed in millibars are 6·2 mb., 12·5 mb., 32 mb., 59 mb., 83 mb., and 1,000 mb. respectively.

TABLE OF SATURATION PRESSURES IN THOUSANDTHS OF AN "ATMOSPHERE" (MILLIBARS).

Temperatures.		Saturation Pressure.
t	F	mb
270	26·6°	4·9
275	35·6°	7·0
280	44·6°	10·0
285	53·6°	13·9
290	62·6°	19·2
295	71·6°	26·2
300	80·6°	35·2
305	89·6°	47·6
310	98·6°	62·1
315	107·6°	81·3
320	116·6°	105·3

The presence of dry air, be its pressure great or small, makes no difference to the final result, but it makes a great difference to the time which will be required for the saturation to be reached. It is a slow process when the dry air pressure is that of the ordinary atmosphere, it is practically instantaneous if there is no dry air present at all, but in every case the evaporation goes on until the "saturation pressure" is reached, and then stops.

A table of saturation pressures of water vapour at different temperatures is given in the table above, and it is represented in the diagram (Fig. 84) which faces it.

We have supposed the space in which the evaporation takes place to be closed because we wished to measure the effect upon the pressure. In the open air we cannot deal with closed spaces, but the pressure and temperature of the free air can be altered, and we must therefore consider the change of state as regards saturation in these circumstances.

So long as the air is not saturated, moist air follows the same laws of expansion and contraction under changes of pressure and temperature as dry air under the same changes of pressure and temperature. Until the condensation point or dew-point is reached, the water vapour in the air behaves

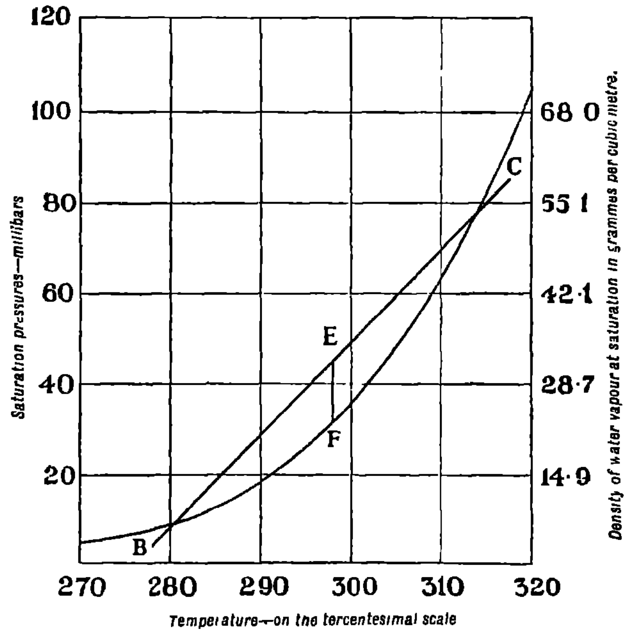


FIG. 84.—Maximum Pressures of Water Vapour in Millibars or Thousandths of an "Atmosphere" at different Temperatures on the Tercentesimal Scale, *i.e.*, in Centigrade Degrees measured from Absolute Zero (273 t. below the melting point of ice.)

like dry air, except that under like conditions of pressure and temperature it only weighs five-eighths of what the same volume of dry air would weigh.

In an unsaturated mixture of dry air and vapour, the dry air and the vapour each bear their proportional share of the pressure throughout any series of changes of pressure and temperature so long as the saturation point is not reached, but if by gradual compression or by a gradual reduction of temperature, the part of the pressure borne by the vapour

reaches the saturation pressure, a new state of things ensues. The water vapour cannot bear any more pressure; further

WATER VAPOUR IN A SATURATED ATMOSPHERE UP TO 30,000 FEET.

Surface Temperature, 50° F., 283 t. A lapse-rate of temperature corresponding with the saturation adiabatic is assumed.

Height above sea-level	Pressure.	Fraction of the pressure borne by the water vapour	Weight of Water Vapour ÷ Weight of Dry Air	Temperature, Tercentesimal Scale	
Feet	mb.			t	
30,000	292	·00010	·00006	220	
29,000	305	·00013	·00007	222	
28,000	320	·00017	·00009	224	
27,000	336	·00021	·00012	226	
26,000	353	·00025	·00015	228	
25,000	370	·00030	·00018	231	
24,000	386	·00035	·00021	233	Freezing point of mercury
23,000	400	·00040	·00025	235	
22,000	417	·00046	·00030	237	
21,000	435	·00063	·00038	240	
20,000	455	·00078	·00047	242	
19,000	478	·00093	·00058	244	
18,000	498	·0011	·00069	246	
17,000	518	·0013	·00081	249	
16,000	539	·0016	·00096	251	
15,000	559	·0019	·0012	253	
14,000	584	·0023	·0014	255	
13,000	611	·0026	·0016	257	
12,000	635	·0030	·0019	259	
11,000	663	·0035	·0022	262	
10,000	689	·0040	·0025	264	
9,000	722	·0046	·0029	266	
8,000	751	·0053	·0033	268	
7,000	781	·0060	·0037	270	
6,000	812	·0067	·0042	272	Freezing point of water
5,000	848	·0076	·0047	274	
4,000	878	·0081	·0052	276	
3,000	910	·0092	·0058	277	
2,000	945	·0101	·0064	279	
1,000	978	·0110	·0069	281	
348	1000	·0117	·0074	282	
Sea-level.	1010	·0121	·0076	283	

operations in the direction of compression, or of cooling, result in condensation of some of the vapour.

Here let me remark that in spite of the vast effects which are the expressions of changes in the quantity of aqueous vapour carried in the air, the mass of water vapour, compared

with the mass of dry air, is astonishingly small. A reference to the table of p. 220 will make this important point clear. The table is prepared to represent the ordinary pressure, temperature and composition of the air as regards water-vapour at different heights up to 30000 feet. It supposes a layer of atmosphere 30000 feet thick, saturated with water-vapour from bottom to top. The temperatures which have been taken at successive heights are those obtained on the assumption that the lapse-rate of temperature is that which would be given by a mass of air lifted from the bottom to the top without any supply or loss of heat. It coincides very nearly with the average lapse-rate of temperature as determined by balloon and kite observations. For the sake of giving definite figures, the temperature at the bottom has been taken to be 50° F., 10° C., 283 t. Such an atmosphere might be churned up mechanically to any extent without producing any final alteration, provided that time be allowed for the water condensed in the rising air to reach the mechanically dried air beneath it. In that sense it is in convective equilibrium.

The columns of the table give first, the height above the bottom (taken as sea-level) in feet, secondly the pressure in millibars, thirdly, the fraction of the pressure which is borne by the water-vapour, the rest being borne by the dry air, fourthly, the fraction of the weight of water-vapour compared with that of dry air, and fifthly, the temperature on the tercentesimal scale.

A study of the figures in the fourth column shows that at sea level and 283 t. the weight of water-vapour is only ·0076. of that of the dry air with which it is mixed, *i.e.*, about three-quarters of one per cent.; at 10,000 feet it is only one quarter of one per cent., at 20,000 feet a half of one-tenth of one per cent., at 30,000 feet a half of one-hundredth of one per cent. These relative magnitudes must strike the reader as being very small, but they are what nature has to deal with on the average in the atmosphere of this country.

It is true that the quantity of water increases very rapidly as higher temperatures are reached. If we take 310 t., 98·6° F,

the normal temperature of the blood, as the highest temperature at which the air has ever been saturated naturally at any point of the earth's surface we may take as much as five per cent. of the mixture to be water.

Near the surface, in equatorial climates, such high temperatures of saturated air are at least possible, and hence the layer of air up to say 20,000 feet in those regions may contain more than five times as much water as that which can be contained in air at the average temperature of these islands, but when we get outside the tropical limits or at the height of, say, the Alps, water becomes universally a small but by no means negligible constituent of the atmosphere.

The dynamical and thermal properties of dry air, pure water vapour and a mixture of dry air and water vapour which we call moist air, are most easily compared by means of diagrams showing the relation between the pressure p which we may suppose to be expressed in fractions of an "atmosphere," or millibars, and the inverse or reciprocal $1/v$ of the volume expressed in cubic centimetres or cubic feet, which the gas, vapour or mixture is allowed to occupy.

We are still supposing that we can control the volume of a limited quantity of gas or mixture, and that the pressure will adjust itself accordingly. For each line of the diagram we shall suppose the temperature fixed. So long as no part of the water is condensed, $1/v$ may be regarded as the density of the gas or mixture, supposing that we are dealing with unit mass; but after condensation has commenced the idea of density must be somewhat modified to make it represent $1/v$.

Changes of temperature will make an alteration in the pressure, so that we shall give two lines, one for 270 t. (26·6° F.), and one for 300 t. (80·6° F.), those being extremes which will include the great majority of temperatures noted in our local atmosphere.

On account of the smallness of the proportion of water to dry air, as explained in previous paragraphs, it is not practicable to draw diagrams for dry air and water-vapour to the same scale

which can be applicable to air near the surface where the pressure is great, but the principle is the same, and the conclusions which we draw will hold.

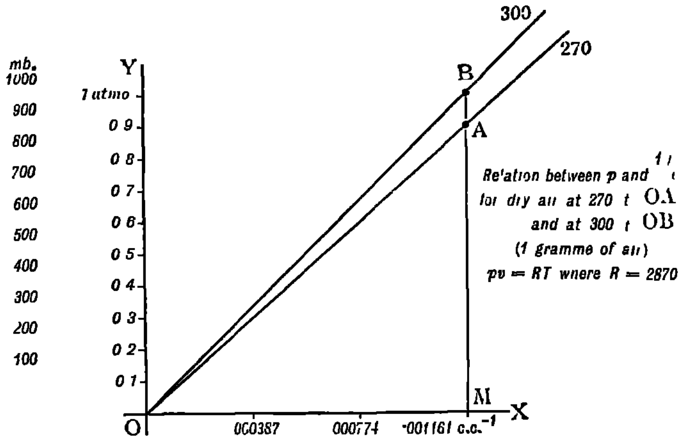


FIG 85.

The two straight lines OA, OB, in Fig. 85, represent the relation between p and $1/v$ for dry air at 270 t. (26·6° F.) and 300 t. (80 6 F.) respectively. The construction of the diagram

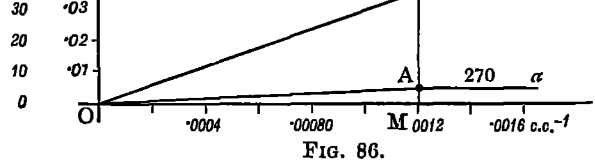


FIG. 86.

is simple; taking OM to represent $1/v$ for a gramme of air at one "atmosphere," represented by MB, when the temperature is 300 t. we get the point B. MA is 270/300 of MB, and the two straight lines joining B and A with O represent the relation

of the changes in pressure and density of the air at 300 t. and 270 t. respectively.

To draw the corresponding diagram for water-vapour (Fig. 86) we shall suppose that in each case saturation pressure is just reached when the space is that which corresponds with dry air at one "atmosphere," 1,000 mb., at 300 t. We can find from the table of saturation pressures (p. 218) what the saturation

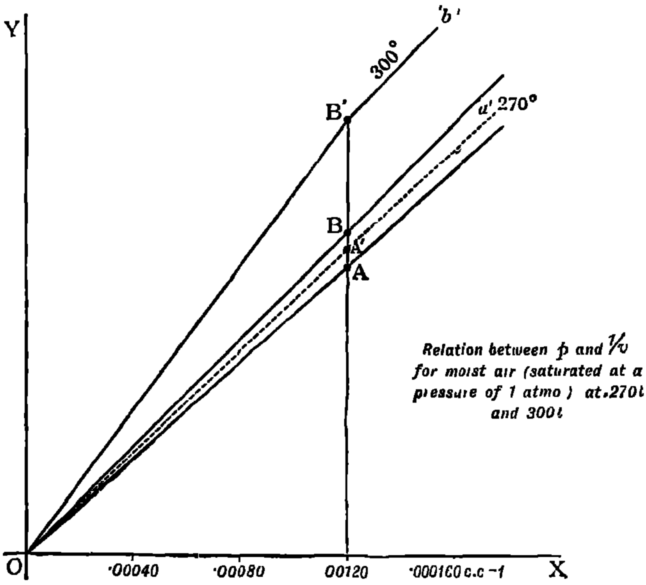


FIG. 87.

pressure at the two temperatures will be. They are 4·9 millibars at 270 t., and 35·2 millibars at 300 t.

Take OM to represent $1/v$ where v is the space which should be saturated—it will be the same value as in Fig. 85—and erect the ordinates MA and MB to represent the saturation pressures 4·9 mb., and 35·2 mb. In the diagram as drawn the scale of these ordinates has been magnified ten-fold as compared with Fig. 85. The straight lines OA and OB joining O with the points A and B represent the relation of changes in pressure, and $1/v$ as the volume is changed. Thus, as the

vapour is compressed and $1/v$ is increased the vapour behaves exactly like a gas until the saturation point A in the one case, or B in the other, is reached, thereafter no further increase of pressure is possible; condensation begins and further compression results in a straight line parallel to OM, at a distance representing the saturation pressure. The lines drawn refer to different amounts of vapour. The amount can be determined from the temperature and volume at which saturation takes place.

Having obtained two diagrams, one for dry air (Fig. 85), and the other for water-vapour (Fig. 86), the diagram for the moist air obtained by mixing the two is found simply by adding the corresponding ordinates of the two as represented in the diagram of Fig. 87.

Thus OB′b′ is got by adding the ordinates of OB of Fig. 85 and of OBb of Fig. 86, and so for OA′a′. It must be remembered that the scale of the second diagram is exaggerated so that no scale can be given for the result, but clearly we get in each case a bent line OA′a′ or OB′b′ to represent the change at 270 t. and 300 t. Each line is suddenly bent at the point where saturation is reached, and thereafter the changes due to compression are the same as the changes in dry air, with an added pressure, *viz.*, the saturation pressure for that temperature.

In the atmosphere changes of volume may be associated with changes of pressure or temperature, so that the complication is considerable, but we have always to remember that there is an essential difference between saturated and unsaturated air. So long as we are dealing with unsaturated air we are on the parts of the lines represented by OA′ and OB′, and the moist air behaves like a true gas; as soon as the saturation point A′ or B′ is reached we pass to the parts of the curve represented by A′a′ or B′b′, where condensation accompanies compression and evaporation accompanies expansion.

Herewith enters another complication. There can be no evaporation unless there is liquid water to be evaporated.

Liquid water can only be present as cloud-drops or rain-drops, and these fall out of range if they are allowed to settle. Hence the condensation represented by moving from B′ to b′ may have no compensating evaporation if the volume be increased again, because the condensed water may have fallen as rain. In that case the return journey will be performed as though the air were unsaturated, that is, the return line will be directed towards O and not along a′A′.

We have still to consider what happens if moist air is compressed or expanded without any precautions for keeping its temperature constant as supposed in the diagram.

So far as sudden or adiabatic compression is concerned there is no appreciable difference between saturated air and dry air, a rise of temperature of 1° C. for every 100 metres of descent is produced, but expansion is a different matter. This produces cooling, and cooling is attended with condensation. The condensation sets free the latent heat of the condensing vapour, and hence the reduction of temperature is less than if the air is dry when it is expanded.

We get in this case the adiabatic cooling of saturated air which depends upon the amount of vapour condensed. Instead of the full cooling of 1° C. for 100 metres of height we get about 0·56° C. for 100 metres. To a certain extent it depends upon the temperature.

The following table gives the temperature in saturated air at successively lower pressures computed on the assumption that the rising air carries the condensed water with it, though no allowance is made for the variation which is caused when the freezing point is passed and the drops of rain freeze and become hailstones. The corresponding fall of temperature for change of height can be determined when the change of pressure with height is known. For approximate calculations an average fall of pressure of 400 mb. for 4,000 metres from the surface is a useful figure to bear in mind.

The values which are in one horizontal row in the table give the temperatures which correspond with successive steps of pressure

SATURATED AIR AND ITS POTENTIAL TEMPERATURES.

Temperatures at specified pressures along lines which correspond with adiabatics of saturated air, starting from specified temperatures at sea-level (pressure 1013·2 mb.), and retaining the condensed water. The last column shows the potential temperature which the air attains during the expansion. This should be compared with the initial temperature of the first column.

Pressure in Millibars.

1013·2	1000	900	800	700	600	500	400	300	200	100	Final Potential Temperature.
t.	t.	t.	t.	t.	t.	t.	t.	t.	t.	t.	t.
303	302·6	299·1	295·2	290·8	285·5	279·0	270·9	260·1	241·0	199·5	384
301	300·5	297·0	293·0	288·3	282·8	275·9	267·7	255·8	234·7	193·0	372
299	298·5	294·9	290·8	285·9	280·0	272·8	264·3	251·2	228·1	—	361
297	296·5	292·8	288·4	283·3	277·3	270·1	260·9	246·5	222·7	—	352
295	294·5	290·7	286·2	280·9	274·5	267·1	257·0	241·6	216·7	—	343
293	292·4	288·4	283·8	278·3	271·7	264·0	253·0	236·8	211·3	—	335
291	290·4	286·3	281·5	275·7	269·2	260·9	249·1	232·0	206·7	—	328
289	288·4	284·2	279·2	273·1	266·4	257·5	245·0	227·5	202·7	—	322
287	286·4	282·0	276·8	270·7	263·6	254·1	241·1	223·2	198·3	—	316
285	284·4	279·7	274·4	268·3	260·7	250·7	237·2	219·2	194·7	—	310
283	282·4	277·6	272·1	265·8	257·8	247·3	233·5	215·2	191·3	—	305
281	280·4	275·4	269·9	263·2	254·9	244·0	229·8	211·7	—	—	300
279	278·4	273·2	267·7	260·7	251·9	240·9	226·6	208·5	—	—	296
277	276·4	271·2	265·3	258·0	249·0	237·5	223·4	205·5	—	—	292
275	274·4	269·1	262·9	255·5	246·0	234·5	220·2	202·5	—	—	288
273	272·4	267·1	260·7	252·9	243·4	231·6	217·4	200·0	—	—	285
271	270·3	264·8	258·2	250·2	240·4	228·7	214·4	197·2	—	—	281
269	268·3	262·6	255·6	247·5	237·6	225·9	211·7	194·8	—	—	277
267	266·3	260·3	253·2	244·9	234·9	223·1	209·0	192·3	—	—	274
265	264·2	258·1	250·9	242·4	232·3	220·5	206·8	—	—	—	271
263	262·2	255·9	248·6	239·9	229·8	218·1	204·4	—	—	—	268
261	260·2	253·7	246·3	237·5	227·4	215·9	202·2	—	—	—	265
259	258·2	251·6	244·0	235·3	225·3	213·6	200·3	—	—	—	262
257	256·2	249·6	242·0	233·3	223·3	211·6	198·4	—	—	—	260
255	254·2	247·4	239·7	230·9	221·0	209·6	196·4	—	—	—	257
253	252·1	245·3	237·6	228·7	218·9	207·6	194·6	—	—	—	255
251	250·1	243·2	235·4	226·6	216·9	205·5	192·6	—	—	—	252

NOTE.—In calculating the temperatures at the specified pressures no allowance has been made for the heat released by the freezing of the condensed water. Its effect is to make a higher temperature correspond with the specified pressures, or a lower pressure correspond with the specified temperatures, at or below the freezing point. The diminution of pressure on this account is 23 mb. for the starting temperature of 303 t. The final potential temperatures of the last column are computed from values of the "total entropy" given in the "Dictionary of Applied Physics" under "Thermodynamics of the Atmosphere."

of 100 mb. along adiabatic lines for saturated air.[1] As the temperature falls and condensation takes place, the heat previously latent and now liberated is taken up by the mixture of air and water-drops and prevents the temperature falling as much as it would do if there were no condensation. Compared with the amount of air, the amount of water is small, as we have already seen. Hence it is the air which profits in the redistribution of the heat. If we consider the amount of water small enough for the heat which it takes to be neglected, we may regard all the heat as contributed to the dry air, and thus by the change of its composition the air obtains heat in spite of the fact that the process is technically adiabatic. When the drops of water fall away, the potential temperature of the air is left raised by the appropriation of the heat.

For many purposes the best way of expressing the existence of potential temperature is to give the "realised entropy" ϕ which is related to the potential temperature θ by the formula:

$$\phi = C_p \log \theta + \text{constant}.$$

But as we do not propose to deal here with the question of entropy, we may be content to use the potential temperature itself as the index for separating successive adiabatic lines. The successive horizontal rows in the table correspond therefore with steps of potential temperature from one saturation adiabatic to another at sea-level. The argument of each row is the potential temperature at the start or sea-level when the pressure is 1013·2 mb. During the course of the expansion more and more entropy will be realised. At the other end of the table is the potential temperature which would be reached when the water has fallen out. It corresponds with the ultimate fate of the air in the successive rows as it becomes more and more rarefied under continuous reduction of pressure. In the calculation of this table no account has been taken of the freezing of the water-drops.

[1] The values were computed by Mr A. W. Lee, M.Sc., of the Imperial College of Science and Technology. Information as to the calculation is given in the article on "Thermodynamics of the Atmosphere," "Dictionary of Applied Physics," vol. 3.

The table is introduced for the purpose of informing the reader as to the changes of temperature which are to be expected in saturated air as it rises from sea-level without any gain or loss of heat to the levels of the lowest pressures within the range of meteorology. The changes which are indicated in it for steps of 100 mb. should be contrasted with the corresponding change in dry air obtained from the formula of p. 212:

$$\frac{\delta T}{T} = \cdot 29 \frac{\delta p}{p}$$

FORMATION OF CLOUD, RAIN, HAIL AND SNOW

The details which we have given respecting the general character of the changes in the temperature and humidity of the atmosphere enable us to approach the question of the formation of cloud, rain, and other forms of precipitation with a general knowledge of the conditions that must obtain during the process. These phenomena all depend upon the condensation of water vapour to water drops or ice particles in the free atmosphere, and the conditions of condensation are an important consideration. Condensation on solid objects gives us dew or hoar-frost; in the free air it gives us cloud, rain, hail or snow.

NUCLEI FOR CONDENSATION

The first point that should be noticed is that to form a water drop in the free atmosphere in what may be called natural or ordinary conditions there must be already existing a nucleus upon which the drop can form. If there is no nucleus there will be no drop although the saturation point has been passed. The nuclei upon which drops can form if the saturation point be passed by ever so little are dust particles of all kinds, soot, sand, pollen grains and other vegetable products, and also some of the gaseous products of the combustion of coal or wood which have a special chemical attraction for water. An enclosed part of the atmosphere can be cleared of the solid nuclei on an experimental scale

by allowing them to settle, and the gaseous nuclei can be removed by causing the formation of drops by rarefaction and letting the drops carry down their nuclei. Thus on the experimental scale we can get air free from nuclei and therefore incapable of giving a cloud although it is cooled, dynamically or otherwise, below the saturation point.[1]

Mr. C. T. R. Wilson has shown that air which is in this condition can be cooled dynamically until a state of "fourfold saturation" is reached without condensation. If cooling is pressed beyond that point condensation begins upon "negative ions," that is, upon dissociated atoms of gas which carry elementary charges of negative electricity and are produced by the dissociation of water-vapour or some other compound. Still higher rarefaction is necessary to produce deposits of moisture on positive ions, that is, upon the dissociated elements of water, or other chemical compound, carrying positive electrification.

It is evident that the condensation upon ions can only be supposed to take place when the dynamical cooling of the air passes a long way beyond the ordinary saturation point and there are no nuclei present. We have already said that a limited quantity of air can be freed from nuclei in the laboratory by appropriate treatment, and there can be no doubt that the precipitation of rain, hail, or snow brings down the nuclei upon which the drops are originally formed; but we have not sufficient evidence to show that a mass of the atmosphere is ever so completely deprived of its ordinary nuclei that it has to be highly supersaturated before further condensation can take place. No sample of free air that has been the subject of investigation has shown any tendency to delayed condensation on account of want of dust nuclei.

[1] This part of the subject is specially associated with the name of the late Mr. J. Aitken, F.R.S., of Falkirk, who applied the method of condensation to counting the dust-particles in air. On the ground of recent investigations in Germany it is now sometimes concluded that the nuclei upon which moisture forms are not ordinary solid dust-particles, but hygroscopic molecules of acids or salts. Filtration through cotton wool removes all nuclei; the effect of "settling" is not quite clear.

It is a point of much interest which may be commended to aviators who are interested in scientific investigation to find out whether above the rain-clouds there are to be found samples of air completely free from dust. It would be convenient in many ways to be able to introduce condensation upon negative ions as a natural physical process in the atmosphere in explanation of certain electrical or other phenomena, but we cannot safely say that the conditions for such condensation are ever attained, and for the present we shall suppose the passing of the saturation-point to be a sufficient condition for the formation of cloud in the free atmosphere.

Ultra-violet light has been proved by Mr. Wilson to have the power of producing cloudy condensation in air which is above the temperature of the dew-point and which is therefore not saturated with water-vapour. If the ultra-violet light of ordinary sunlight were capable of causing condensation in air at the surface which is below the point of saturation the result would be a very different distribution of cloudiness from that to which we are accustomed. We refer to this again in Chapter XVI.

CONDITIONS FOR THE FORMATION OF CLOUD

In order that air may pass the saturation point it must be sufficiently cooled. In the free atmosphere protected from contact with the ground no appreciable cooling can take place by means of conduction. Loss of heat by radiation can only take place effectively at night, when there is a possibility of radiation to the clear sky largely in excess of that received from the relatively warm earth. In the day time either the atmosphere is solarised, and then warming would take place, or there is an intervening layer of cloud, in which case the radiation process becomes more complicated, but is certainly reduced in effectiveness. Clouds form at all hours of the day and night, and hence we cannot lay much stress upon radiation as a part of the ordinary process in the formation of cloud.

CONDENSATION BY MIXING

A mixture with a temperature below the saturation point may be obtained if two masses of moist air at different temperatures mix. The capacity of air for moisture increases numerically faster than its temperature, and hence it may result that two masses of air of different temperatures, neither of which is actually saturated, gives a mixture at mean temperature which is more than saturated. For example, if we have a cubic foot of saturated air at the pressure of an "atmosphere" and the temperature 285 t. the water-vapour within it will bear ·015 of the pressure and in a cubic foot at 275 t. the water-vapour will bear ·007 of the pressure. If the two volumes were mixed without any condensation taking place, the two cubic feet would share the temperature and the vapour-pressure between them; thus the mixture would have a temperature of 280 t. (45° F.) approximately, and the water-vapour would have to bear ·011 of the pressure. But the saturation pressure at 280 t. is only ·010 of the pressure, so the mixture cannot exert so much as ·011. It would have to lose enough water to reduce the pressure by ·001 of an "atmosphere." I have supposed the two specimens actually saturated; it is clear that either or both might be just short of saturation and yet carry more than enough water to saturate the mixture. But the amount of water produced in this way is very small. A difference of 18° F. (10 t.) is a very large one to expect between two adjacent masses of air in nature, and, even so, two columns 1,000 feet thick would, by mixing, produce less than $\frac{1}{800}$th of a foot depth of water, that is, less than ·015 inch of rain.

The effect of mixing different masses of air has been expressed and explained very clearly by G. I. Taylor in a paper on "The Formation of Fog and Mist." [1] He gives a diagram corresponding with that of Fig. 84 providing for it a scale of ordinates on the left-hand side which gives the proportion of water in the air for

[1] "Q. J. Roy. Met. Soc.," vol. 43, p. 241, 1917.

the corresponding values of vapour-pressure. He shows that if two masses of air whose conditions are represented by B and C are mixed together, the temperature of the mixture and quantity of water-vapour will be represented by some point E on the line BC nearer to B or nearer to C according to the quantity of the two samples. If E lies on the side of the curve of saturation-pressure that belongs to higher temperature, no condensation will result from the mixture; but if E lies on the side of lower temperature, condensation will take place because the vapour-pressure cannot exceed the saturation-limit. If EF be drawn along the line of constant temperature to the point F on the saturation curve, the reduction of vapour-pressure due to the condensation on mixing is indicated by the length of EF, and this can be interpreted as a quantity of water by the scale of proportion at the side.

DYNAMICAL COOLING OF SATURATED AIR

The other process for the condensation of water vapour in the free air is dynamical cooling, that is, the cooling by the reduction of pressure which follows automatically from lifting air to a greater height. The reduction of temperature on this account is at the rate of 1° F. for 300 feet (·56° C. for 100 metres). With air originally at 51° F. (285 t.) a reduction of temperature of ·2° F. (·11 t.) is necessary to eliminate water to the extent of ·001 "atmosphere." Hence the lifting of one 1,000 feet column through 60 feet would produce the same amount of precipitation as the mixing of two 1,000 feet columns at 54° F. (285 t.) and 36° F. (275 t.).

If we wish to assign to their respective causes the formation of cloud and rain in any particular case, we have to consider either the direct evidence for elevation, which will produce condensation, or for mixing, or, in the absence of any direct evidence, the possibility of the existence of conditions favourable for elevation or for mixing. In the case of clouds of the cumulus type, which are closely allied in shape and character with the towering clouds which produce the heavy rain of

thunderstorms, the evidence for ascent is sufficient, and such clouds are universally regarded as due to dynamical cooling. On the other hand, surface fog, which forms on the ground in low-lying areas, cannot be due to dynamical cooling because the possibility of elevation is ruled out. Hence we may conclude that surface fog, however thick it may ultimately become, must be ascribed to the gradual mixing of air of unequal temperatures, the warmer air being already saturated. It is possible in this way, by assuming the gradual gravitation of cold air into the valleys where the surface air is already saturated by standing over comparatively warm water, to account for the frequent formation of land fog in autumn and similarly to explain the formation of fog at sea either by the drift of cold air over warm water or more frequently by the gradual cooling of air as it passes over cold water and the mixing which then takes place in the layers close to the surface.

About the formation of cloud in other cases it is difficult to give any conclusive evidence. It is scarcely possible to imagine circumstances in which we could postulate the mixing of a sufficient quantity of air at different temperatures to produce any considerable amount of rainfall, but it is by no means difficult to imagine circumstances in which elevation of air must go on as a continuous process, so that opinion is gradually crystallising in the sense that rainfall in any considerable quantity is due exclusively to dynamical cooling.

As to the formation of cloud, no such definite conclusion is reached. On the one hand we have to take account of the fact that on some days there are persistent clouds which roll along all day without any rain falling, and it is difficult to imagine a state of things in which elevation goes on for a whole day just enough to form cloud and nothing more. Such a fine adjustment would be impracticable in any laboratory experiment, and therefore one naturally inclines to mixing as an explanation of the phenomenon; but, on the other hand, mixing requires the juxtaposition of two currents of different

temperatures maintained for long hours together. Observations in the upper air go to show that the transition from one current to another in a different direction is either a very gradual alteration of direction without much change of velocity, or a gradual falling off to a calm stratum with a recovery higher up of motion in a different direction.

We are therefore left in this position, that cumulus clouds, rain clouds and rain must be regarded as due to dynamical cooling, that surface fog is certainly due to mixing, and as regards the other forms of cloud, cirrus, cirro-stratus, cirro-cumulus, alto-stratus, and strato-cumulus, the question is left open for further information and inquiry.

CLOUDS FORMED BY TURBULENCE

The opening for further inquiry which was suggested in the last paragraph was utilised as early as 1913 by G. I. Taylor in the voyage of the *Scotia*, which was sent out by the Board of Trade in the spring of that year to obtain information respecting ice in the Atlantic Ocean. Public attention had been drawn to the dangers of ignorance concerning ice by the loss of the S.S. *Titanic*, a huge White Star liner that was lost on April 15, 1912, by crashing into an iceberg. The report of Mr. Taylor's work formed part of the official report of the voyage of the *Scotia*.[1] It contains the results of a number of observations of temperature and humidity in and above fogs on the banks of Newfoundland and shows that the normal condition for a fog at the surface is water a little colder than the air above it. The temperature increases continuously upwards through the fog and above it until a maximum is reached at the level of 1,000 metres, and then the lapse of temperature with height sets in, which is generally characteristic of the atmosphere all over the world. The exceptions are the so-called isothermal regions or inversions of the stratosphere which are to be found always above a certain level depending upon latitude and weather, somewhere between

[1] Report on the work carried out by S.S. *Scotia*, 1913. 1914.

6,000 metres and 18,000 metres, the regions of relatively cold sea-surface and the cold ground of Arctic or Antarctic countries in winter, and occasional inversions at various levels in the atmosphere as the result of thermal and dynamical changes. Taylor has further investigated this subject from the theoretical point of view and has calculated the reduction of temperature of the air above the sea, in consequence of the mixing of the surface layers with the upper layers by eddy-motion which produces a form of diffusion on a large scale and carries the cold air upwards according to the same law as that by which diffusion carries the molecules of a heavy liquid into a lighter layer above it. The formal representation of both eddy-diffusion and the more familiar molecular diffusion is the same, but the coefficient in the one case is so much larger than in the other that in the course of hours under ordinary conditions the mixing will have reached 100 metres or more; far more rapidly, that is to say, than anything which could be accomplished by molecular diffusion.

Eddy-motion thus interpreted has another application of considerable importance in the formation of cloud. Its operation in lifting upwards the surface-air is not confined to the cases when the surface air is cold and the process of mixing which follows upon the motion produces fog. The mere lifting of the air in the eddies causes a reduction of the temperature. By loading the air with smoke as by a chimney it may be noticed that the air, which at one moment is in the neighbourhood of a point, as, for example, the orifice of the chimney, is subsequently dispersed over an area which is represented approximately in vertical section by a parabola with horizontal axis having its vertex close to the point at which the smoke was delivered. So we must regard air in the turbulent motion due to the friction of the ground as climbing upwards, first rapidly, then with gradually diminishing velocity, but still rising. And the elevation will cause a corresponding fall of temperature, and when that passes beyond a certain limit clouds will be formed, not at the surface, but at an elevation which depends upon the original temperature and humidity of the air.

Hence clouds may be formed by the merely mechanical effects of friction causing eddy-motion and consequent elevation of the moist air of the surface to heights that are sufficient to cause condensation. The investigations which are thus briefly indicated give new ideas as to the formation of cloud layers. A cloud layer may be the boundary where the elevation of the surface air by the eddying process is sufficient to cause condensation. We may thus find the explanation of the formation of many of our commonest and most widespread forms of cloud; the stratus, with its horizontal lower surface, the strato-cumulus, our ordinary cloudy sky, and possibly in some way which is not yet entirely clear, the other layers of cloud, alto-stratus, cirro-stratus, alto-cumulus and cirro-cumulus.

The formation of cloud in this way is different from the formation of a single cumulus cloud which may be ascribed directly to the ascent of air through an environment than which it finds itself to be lighter. But not infrequently the two causes seem to act in co-operation. The eddy-motion acts dynamically. It is not dependent upon thermal conditions, though it may be enhanced or reduced by them, and its effect may be to carry the lower air upwards to regions where it finds itself lighter than its environment and thus in condition to form cumulus cloud. In this way we may perhaps explain the dotting of the whole sky with detached cumulus clouds such as may occasionally be seen with a northerly or north-easterly wind in our own southern districts and can always be found in the trade-winds where they have acquired the special name of trade-wind-cumulus.

HAIL

When we pass from the consideration of the formation of rain to that of the other forms of precipitation we find a number of interesting questions. The size of raindrops is limited because, if they travel through the air at a rate which exceeds a limiting speed, they break up; the larger the drop, the smaller is the limiting speed. A drop of rain may therefore have a lengthy experience in the atmosphere. Commenc-

ing in consequence of a rising current, it may ultimately get beyond the limits of the current which produced it. Then it falls, and its velocity will be accelerated up to a certain limit depending upon its size, according to a law enunciated by Stokes. Lenard has shown that if it travels fast enough it breaks up into smaller drops.[1] The upward motion may be strong enough to carry up the fragments of the broken drop though it could not stop the original mass. Thus we may picture to ourselves a drop that falls downward until it breaks into pieces and the pieces are carried up again; they may increase in size again owing to further condensation by dynamical cooling and, being thrown out of the rising column fall again and may possibly be broken up again. If at any stage of this process the temperature is low enough to freeze the drop we get the nucleus of a hailstone. Thereafter any breaking up into pieces in consequence of the rate of fall must be confined to the water condensed upon the outer surface, the interior core of ice must be left, and thus throughout its successive journeys the hailstone preserves in the details of its structure a record of its history. Finally, when it leaves the rising current it may have attained considerable dimensions, and it then falls to the earth a veritable missile.

The theory of the breaking up of raindrops after they reach a limiting velocity of travel through the air is confirmed by the fact that raindrops never exceed a moderate magnitude that is not capable of doing mechanical damage, whereas hailstones sometimes reach very substantial and destructive magnitude. In the mode of formation there can be no difference, but in the occurrence of hailstones by the freezing of raindrops there is very strong evidence of the considerable magnitude of the rising currents in which they are produced. The difference of structure in different layers shows that they have passed through an eventful history, during which they must have been supported by rising currents. Hence the occurrence of hail may be taken as evidence of violent commotions in the

[1] See "Quarterly Journal, Roy. Met. Soc.," Vol. 31, p. 62, 1905.

atmosphere with strong upward currents which, so far as we know, must have been preceded by some instability of the atmospheric layers.

SNOW

In this country snow is the forecaster's greatest difficulty. The difference between a heavy snowfall and a heavy rainfall in its effects upon human life and business is incalculable. There are two elements against which man is ultimately powerless, viz., snow and drifting sand. If either of them is continued sufficiently long, human effort is unavailing. Consequently, there is no occurrence which it is more important to forecast with accuracy than a heavy snowfall. Yet we cannot at present distinguish adequately between the conditions for rain and the conditions for snow. Nor do we know the conditions for the condensation of the atmospheric vapour in the form of snow. In polar regions the atmospheric precipitation is in the form of fine ice crystals; what is the secret of the formation of large snowflakes we do not know. So far as I am aware nobody has yet succeeded in demonstrating the formation of snow in the laboratory. Hoar frost on refrigerating pipes is common enough, but condensation to ice in the air itself is beyond my experience. Water drops can be easily "supercooled," that is, cooled below the freezing point without becoming ice and I have never yet seen an ice cloud formed artificially.[1] However cold it may be, the artificial cloud shows the iridescence of the corona, not the detached circle of the halo. Yet the occurrence of the halo in nature is clear proof of the existence of refracting crystals of ice, for spherical globules of water produce no halo. Whether the large snowflake is formed by the aggregation of smaller crystals or the extension of a crystalline nucleus by condensation we do not know. Nor do we know whether snow is often formed and

[1] After this sentence was written my friend and predecessor, Mr. R. H. Scott, reminded me of an occurrence at an international meeting in Petrograd, when the opening of a window allowed the ingress of very cold air into the warm moist atmosphere of a crowded room. The result was a visible shower of snow in the room.

melts before reaching the ground, whether the mixture of rain and snow which we call "sleet" was originally all snow and is partly melted, or was all rain and is partly frozen. All that we do at present is to anticipate snow or rain if the conditions are rainy and the surface temperature is near the freezing point, but the value to the public of an accurate forecast of snow is so great and so obvious that the subject deserves much greater attention than it has hitherto received.

CONDITIONS FOR THE ASCENT OF AIR, CONVERGENCE, JUXTAPOSITION AND ATMOSPHERIC INSTABILITY

We have seen that rain or any other form of precipitation is generally to be attributed to the effect of a dynamical cooling of air in an ascending current, and we shall conclude this chapter by considering the conditions to which the ascending current may be due.

The most obvious suggestion of the cause of an ascending current is the heating of the surface layer by the action of the soil warmed by the sun's rays, or by the effect of warm sea-water upon a cold layer of air above it. These causes no doubt produce ascents of air, but it is not easy to say how far the effect extends or how far it is operative in meteorological changes. Heated air will not rise unless there is a denser air either beside it or above it ready to push it up, and when we are dealing with a large area of land it is not easy to find the necessary cold air to take its place. The surface heating, indeed, does not necessarily mean an ascending column; it often expresses itself as ascending threads of warm air which produce the shimmering commonly seen over sand heated by the sun, and the only effect is the warming of the surface layers up to a certain height and their cooling again on the subsequent night, the whole being, so to speak, self-contained. There are occasions when rain and even thunderstorms may be ascribed to the effect of warm sea or warmed land upon the air above it, but the examples are comparatively rare. In ordinary circumstances the air seems to have greater stability, and the

effect of the surface heating does not reach any great height.

CONVERGENCE OF STREAM LINES

A more effective cause of an ascending current is that associated with convergence of the air currents from different sides towards a centre, or the convergence of lines of flow in what may be called the same current. It may be difficult to say whether this convergence of the air is to be regarded as the cause or the result of the ascending current, but at present the distinction need not concern us. We may be content to know that the convergence cannot occur unless there is an upward current to take off the air.

A special form of convergence is the crossing of two currents which are inclined to one another at a finite angle, as, for example, when a southerly wind advances towards the flank of an easterly current or is itself invaded by a westerly wind.

CURRENTS OF DIFFERENT TEMPERATURES IN JUXTAPOSITION.

Examples are frequently to be seen on maps in which a broad air current is supplied by air from two different sources, so that the two separate streams run side by side. These are sometimes of very different temperatures, and in consequence we get two currents of different temperatures in juxtaposition. In that case the cold current may spread out under the warm current and push up the warm current, and thus produce elevation and consequent condensation. This process seems to be a regular phenomenon in connection with line squalls which are dealt with in Chapter XI.

INSTABILITY IN THE ATMOSPHERE

By instability in the atmosphere I mean a condition of affairs where a lighter layer is found with a heavier layer above it, so that the lighter layer breaks through the layer above and thereby causes an upward current that is violent until stable equilibrium is reached.

Instability in the atmosphere must be of frequent occurrence. It affords the only explanation which we can offer of sudden heavy showers, thunderstorm rains, hailstorms, and similar phenomena. It is difficult to see how instability can arise in such a way as to cause such violent effects. If any portion of the surface air becomes warmed relatively to the surroundings it can rise immediately; there is no reason to suppose that it will wait until a reservoir of instability has been formed that will develop almost explosive violence. Instability will, however, arise if two superposed layers of atmosphere have different degrees of humidity and are elevated or depressed in a regular manner. For example, if a layer of dry air is formed above a layer of cloud, as is not infrequently the case, and the double layer is elevated, the upper layer will cool with the dry adiabatic gradient and the lower layer with only the saturated adiabatic gradient; hence the upper layer will cool nearly twice as fast as the lower, and a sufficient elevation will produce instability.

On the other hand, suppose a layer of cloud over a layer of air free from cloud, and suppose the double layer to be depressed. The temperature of the lower layer will rise nearly twice as fast as that of the cloudy layer, and a sufficient depression will certainly produce instability if there is water enough in the cloud to supply the demand for evaporation due to dynamical warming.

The tendency to stratification in the atmosphere is quite a noticeable feature[1]: clouds often seem to form at the same level over great areas. When the stratification becomes complex and there are successive layers of different composition and in different physical states, there must always be a possibility of instability by the upheaval or depression of superposed layers. Instability might also be produced by the gradual warming of the lowest stratum of air through prolonged

[1] I have shown elsewhere that stratification is the normal consequence of the distribution of realised entropy or of potential temperature in the atmosphere in such a way that the value increases with height. In a perfectly labile atmosphere the potential temperature should be the same everywhere.

solarisation accompanied by evaporation of water, under a current unaffected by the surface heating. The increase in humidity may result in the pushing upward of air into the upper layer, accompanied by the formation of cloud and consequent instability.

It seems possible also that instability might arise in circumstances which are familiar in the example of an upper current

1909. June 1, 7 a.m.

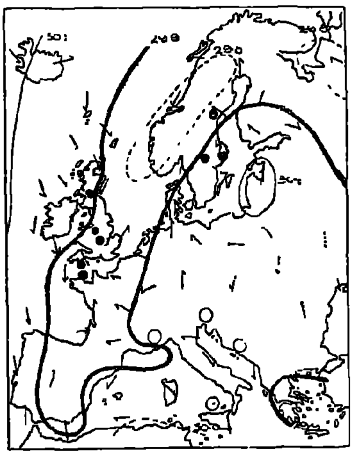


Fig. 88.—Chart illustrating the Convergence of Air in a Belt of Low Pressure.

1908. November 7, 6 p.m.

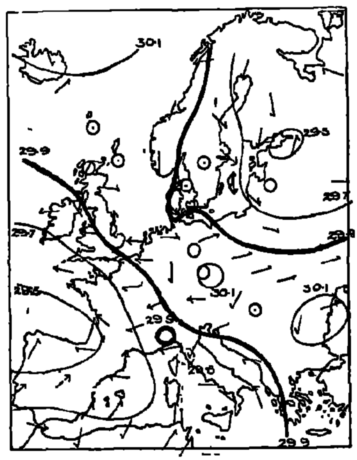


Fig. 89.—Chart illustrating the Divergence of Air in an Anticyclonic Belt.

from the north-west crossing a lower current from the south-west. If the conditions are persistent, the temperature of the upper current coming from the northward may become lower or at least remain constant while the temperature of the lower current supplied from equatorial regions may rise until it is no longer in equilibrium under the upper current. The circumstances are sketched in a paper on the interpretation of the results of observations with pilot balloons in the "Quarterly Journal of the Royal Meteorological Society," Vol. 40, 1914, p. 111.

In illustration of the general application of the principles set out in this chapter to the conditions of weather as repre-

sented on synchronous charts, I wish to call attention to the charts for 6 p.m. of November 7, 1908 (Fig. 89). and 7 a.m. of June 1, 1909 (Fig. 88), which have been brought to my notice in connection with Mr. C. J. P. Cave's investigation of the upper air by means of pilot balloons. The regions to which I wish specially to refer are those represented on the

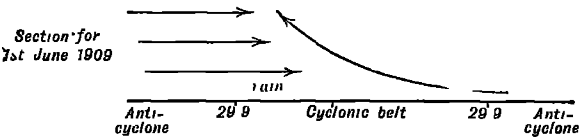


FIG. 90.—Probable Courses of the Flow of Air in a Section across the Belt of Low Pressure of Fig. 88.

two several maps as lying between the two more or less parallel courses of the isobar of 29·9 inches. In the June map the isobar is shown as a continuous one by a turn over Spain; in the November map the two isobars are, so far as one can tell from the map, separate, but the difference is unim-

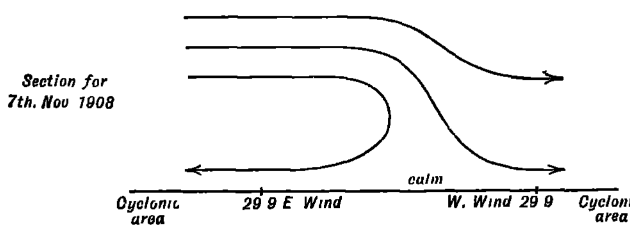


FIG. 91.—Probable Courses of the Flow of Air in a Section across the Belt of High Pressure of Fig. 89.

portant. In the June map the long fronts of two anticyclones face each other with a strip of low pressure between them; in the November map the long fronts of two cyclonic areas face one another with a strip of high pressure between them. On the former occasion, June 1, winds are shown approaching the cyclonic strip from the north-west on the one side and generally from the east on the other; on the latter, November 7, winds are very clearly shown receding from the anticyclonic strip to

the west on the one side and to the east on the other. A line of calms marks the separation between the two surface currents. We cannot avoid the conclusion that on June 1, the approaching currents of air ascend in the cyclonic region, and on November 7 the line of calms is the locus of descending air which feeds both the easterly and the westerly winds. These conclusions are confirmed in various ways. As regards June 1, Mr. Cave found a south-easterly current over the surface north-westerly air, and at the same time rain was falling at the stations indicated by black dots on the map, thus affording undeniable evidence of the existence of an ascending current. On November 7 at two to four kilometres a westerly wind was found above the easterly drift of the surface, and the fine weather of the anticyclonic strip is clearly evidence of the reverse of the rain of June 1; it implies descending air. We may therefore represent the vertical section of the atmosphere between the 29·9 lines in these two exceptionally simple cases by the two figures 90 and 91 where the arrows show the courses of the current with reference to the line of the 29·9 in. isobars.

THE THERMAL RELATIONS OF FLOATING CLOUDS.[1]

As an example of the application of thermodynamical principles to the explanation of meteorological phenomena I reproduce here an endeavour to explain the French proverb, "La lune mange les nuages."

It is always difficult to be sure that different persons are in agreement in identifying meteorological phenomena, and I will therefore state in a few words the conditions to which, according to my notions, the French proverb refers.

A single layer of drifting fleecy clouds—strato-cumulus—is rendered visible by the illumination of the Moon not very long after sunset. The illumination not only shows the clouds, but shows that they are diminishing, and finally the Moon is

[1] Reprinted from the "Quarterly Journal of the Royal Meteorological Society, Vol. 28. No. 122 April, 1902.

left in possession of an unusually clear sky. If this is not a correct description of the phenomena to which the proverb refers, it describes a state of things for which I desire to suggest a physical explanation which is not without interest.

I will put the matter in another way:—A floating cloud, a finite mass of air carrying water particles, is losing heat by radiating into space through the clear air above it more heat than it receives from the earth beneath; the water globules will, in consequence of this loss of heat, evaporate, and the cloud will vanish. The converse of this proposition may be stated in slightly different form, thus: A floating cloud is receiving heat from the sun above and the earth beneath, and in consequence of this gain of heat condensation will take place, and the cloud become thicker.

These statements are paradoxical, and to exaggerate the apparent paradox it is only necessary to point out that, as the cloud consists of saturated air, evaporation means a rise of temperature, condensation a fall of temperature; for evaporation implies more vapour in the gaseous form, which is only possible at a higher temperature, and *vice versâ*. So we may reduce the proposition from the meteorological form to a more conventionally physical one, and say that the abstraction of heat from a floating mixture of air and water will cause elevation of its temperature, or briefly, will warm the mixture, whereas the addition of heat will cool it.

The explanation of the apparent paradox is a simple one, as may be seen from the following consideration:—

Suppose a mass of moist air at the surface of the earth to be warmed: it rises, and in consequence expands adiabatically and cools. Suppose that it rises just sufficiently high to form a cloud: then if it had been less warmed it would not have risen high enough for condensation to take place. If it had been more warmed it would have risen higher, and a cloud might have been formed even denser than in the first case. Supplying less heat before the condensation took place is, of course, equivalent to removing some after the first condensa-

tion occurred; one side of the *proposition* follows, therefore, at once, if we can assume that the cloud was formed by the adiabatic cooling of rising air. It is, of course, the changes of pressure incidental to differences of level (due to change of density) which produce the paradoxical thermal effects. But although this mode of treating the problem shows well enough that a cloud which is losing heat by radiation into space will grow warmer and disappear, it does not give any satisfactory proof that the cloud would grow thicker if the sun shone upon it.

The course of events for a floating cloud can, however, be very clearly followed out by means of Hertz's diagram of thermal lines for moist air, which is published in Vol. I. of the "Meteorologische Zeitschrift," and is reproduced in Waldo's "Modern Meteorology." The diagram represents the state of a mixture of air and water under varying conditions of pressure and temperature, the lines of reference being set out according to the logarithms of the pressure, and of the temperature from absolute zero. Since the pressure scale is logarithmic, equal intervals along it correspond approximately to equal steps of height in the atmosphere. The adiabatic lines for different stadia, and the lines of saturation for given percentage composition, enable all the changes in thickness of a cloud under varying quantities of heat to be followed. The diagram is approximate only, but sufficiently nearly accurate to indicate satisfactorily the changes that take place in floating cloud. For this purpose we must add to the diagram a line indicating the relation of temperature and height, or pressure, for the atmosphere in equilibrium, *i.e.*, the line of temperature-lapse. This, of course, is a variable line, depending on the condition of the upper atmosphere for the time being; but supposing, for example, the lapse-rate of temperature to be uniform, and equal to 0·5° C. for every hundred metres (as given by Berson's figures for heights up to 2,000 metres), we get a line across the diagram nearly straight, and dropping one degree in

temperature for every 200 metres of height, as shown at the base of the diagram. The direction of the line being fixed, its position on the diagram must be defined by drawing it in the proper direction through a selected point representing the condition of a floating cloud. We may take a water cloud just above the freezing point, say at 5° C., at 1,200 metres height. Through the point identified by these conditions we

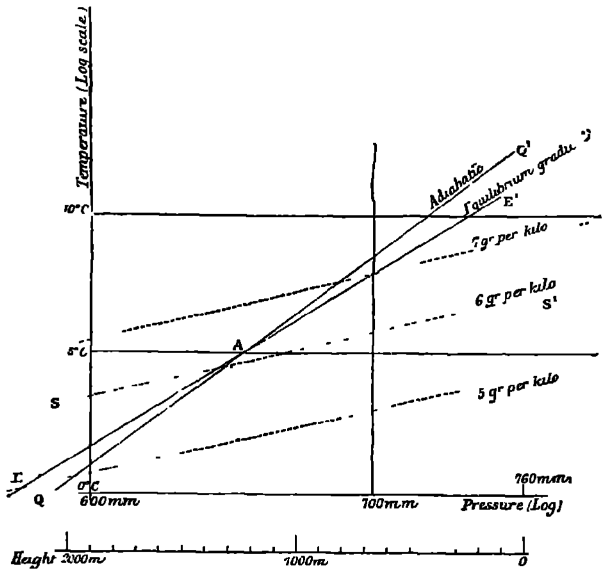


FIG. 92.—Diagram of Thermal Lines for Saturated Air.

can draw the equilibrium line of temperature, and know that, whatever be the initial state of a mass of air, it will rise or sink, following the changes which Hertz's diagram represents, until the equilibrium line is reached. In Fig. 92 certain parts of Hertz's diagram are reproduced, and the equilibrium line is added. The point A represents the state of the floating cloud at 5° C. at 1,200 metres, saturated with about 6·2 grammes of water-vapour per kilogramme of mixture, as indicated by its position with reference to the saturation lines which are dotted in the figure. QAQ′ is the adiabatic line for saturated

air. SS′ the saturation line for 6 grammes of moisture per kilogramme of mixture: the dotted lines parallel to this on either side represent the saturation lines for 7 grammes and 5 grammes respectively. EAE′ represents the equilibrium or temperature lapse line. This line is a little less steep than the adiabatic lines for saturated air, but decidedly more steep than the saturation lines. If we start from the point A on the equilibrium line, representing the condition of the floating cloud, the addition of heat (supposing the cloud always to rise until it recovers its equilibrium) means that the point will travel along the equilibrium line AE to the left; the temperature will fall, since the slope is downward; and, since the equilibrium line is steeper than the saturation line, the point will pass into the part of the diagram where saturation requires less moisture—in other words, condensation will take place. Abstracting heat, on the other hand, means travelling along the equilibrium line in the opposite direction AE′; the air passes into a region where more water is required for saturation. Hence evaporation takes place. Since the slope of the equilibrium line is upward, the temperature rises.

It is interesting to note that the result of warming a mass of floating air depends upon the lapse-rate of temperature of the air in which it floats. If the law of fall of temperature with height were the adiabatic law, a mass of air at the foot warmed ever so little above its surroundings would rise without limit. An inversion of temperature, on the other hand, would at once prevent any rise taking place, or speedily arrest it. A lapse-rate of temperature exactly parallel to the saturation line would indicate the conditions under which a cloud might receive or lose heat and change its temperature without any evaporation or condensation taking place.

It thus appears that, in considering the properties of floating masses of air, except in cases of an "inversion of temperature," or of a zero lapse of temperature, meteorologists have to remember that the ordinary relations between the increase of heat and increase of temperature may be reversed.

It is, of course, possible to suggest other physical explanations for the disappearance of clouds in accordance with the French proverb, and my excuse for suggesting one which may seem fanciful is, that it brings into prominence certain physical relations which are certainly real and are not generally noticed.

I ought to add a word with regard to the conveying of heat to a cloud by radiation. I have spoken as though the distribution took place throughout the cloud, and not, as would possibly appear more likely, at the upper or lower surface only. Although the confining of the addition of heat to the outer portions only would not affect the physical principles involved, I may mention in defence of these views that the clouds in question are generally very thin and very translucent, so that every part of the cloud is illuminated by the Moon's rays, and consequently is exposed to other sources of radiation.

The extent to which clouds can absorb or emit radiation has not yet been ascertained, but there is no question that they are more effective radiators and absorbers than clear air.

It will be noticed that I have passed over any suggestion that the lunar radiation itself adds heat to the cloud. Possibly it does, but the amount of heat so gained must in any case be small compared with that lost by radiation to the rest of a clear sky, so that any effect of direct radiation from the Moon may be quite properly disregarded.

The effect of difference of the lapse-rate of temperature upon the increase or diminution of density of floating clouds with accession of heat, is one that may have many other applications than the one here referred to. It would seem, for example, to furnish a criterion for determining whether the action of the sun upon mist lying on the ground would result in dispersion of the mist, or the lifting of the mass as a cloud either directly upwards, or possibly creeping along a hillside till the top is reached.

The observations of lapse-rate of temperature by the ascent of kites afford facilities for testing by observation the effects which have here been theoretically indicated.

I have put together an arrangement of apparatus whereby the conditions applicable in the case of a floating cloud can be experimentally realised. The essential condition of the arrangement is, that the communication of heat to a limited mass of air shall result in a diminution of the pressure of the air, just as the communication of heat to a floating cloud results in the diminution of pressure as the cloud rises to a higher level. In the apparatus the necessary condition is secured by using a movable cistern of mercury to close the vessel containing the moist air. For this purpose the air is

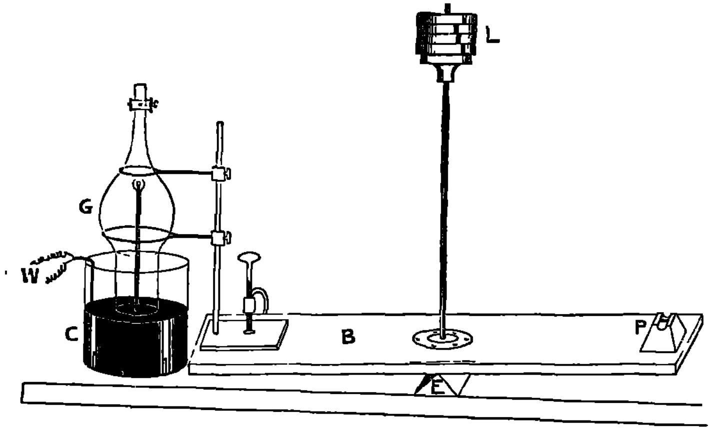


FIG. 93.—Apparatus to illustrate the cooling of air by adding heat.

conveniently contained in a globe, G (Fig. 93), surmounting a vertical tube open at the bottom. The globe with its vertical tube is fixed in a stand, and the open bottom of the tube dips into the mercury in the cistern, C. The stand carrying the globe rests upon one end of a board, B, about five feet long, which is balanced upon a knife-edge, E, the globe and stand are counterpoised by suitable weights, P (about 3 lbs.) at the other end of the board. The globe is thus supported by one arm of a rough balance, and, since all the weights on the balance are above the point of support, the balance, regarded apart from the effect of the elasticity of the air in the globe, is unstable. The instability

is the essential feature of the arrangement, and is largely exaggerated by mounting masses of iron, L, on a rod attached to the middle of the balancing board, so that the head is about four feet above the board. The globe is provided with a narrow neck and stop-cock, to allow it to be filled with saturated and nucleus-laden air at pleasure ; but during an experiment the aperture is closed. The globe dips into mercury in a jar which stands close to the balance. Wires, W, are led through glass tubes to the interior of the globe and connected by means of a fine platinum wire, to allow heat to be supplied to the air at pleasure by passing an electric current through the fine wire.

When the globe has been filled with suitable air, and the aperture closed, any motion of the board diminishes or increases the pressure in the interior by the motion of the globe. The increase or diminution of pressure tends to resist the motion of the board, and by adjusting the positions of the counterpoise and the weight, the arrangement can be made to balance just within the limits of stability, when the elasticity of the enclosed air is taken into account. When this adjustment is made, it is clear that a slight motion of the board in the direction of increasing the volume of the enclosed air throws over the weight towards the side opposite to the globe, and brings to bear a largely increased moment of forces tending to continue the expansion ; so that the ultimate expansion resulting from any cause tending to lift the balance on the globe side produces a rarefaction depending on the degree of dynamical instability of the balance. Such a cause arises when the air in the globe is slightly warmed by passing a current through the wire. As the balanced globe is movable, the balance comes over, and then the dynamical instability causes expansion, determined not solely by the amount of heat which originated the motion, but by the loads on the balance and their position.

The success of the experiment, for the demonstration of the production of a cloud—*i.e.*, a diminution of temperature—on heating, depends upon the proper selection of the area of the dipping tube in comparison with the volume of the globe. A

globe of the shape indicated in the figure gave completely satisfactory results. The counterpoising weights are about three pounds on each side, and the dead weight with iron stand supporting it perhaps fifteen pounds. Under these conditions, with the globe filled with saturated air and properly counterpoised, the commencement of heating at once determines an elevation of the board on the globe side, a rarefaction corresponding to about three-quarters of an inch of mercury and an abundant cloud. The experiment can be repeated with the same air, after readjusting the balance, until the exhaustion of nuclei for the deposit of globules makes the arrangement insensitive. Its activity can always be restored by refilling it with suitable air.

The degree of instability of the balance corresponds to the lapse of temperature with height in nature. I have not yet formed an estimate of the lapse-rate of temperature to which my arrangement of the apparatus would correspond. But the analogy between the two is formally correct, and with a slight modification of the apparatus the equivalent lapse-rate of temperature could be determined. The globe of air rises with increase of heat, and the arrangement becomes simply an apparatus for multiplying the effect of the rise, a rise of two inches with my apparatus being equivalent to a rise of about five hundred feet in nature. It thus becomes a comparatively simple means of conducting in the laboratory operations which really take place on a large scale in nature.

CLEARING OF THE SKY AT SUNSET

During the war the gradual clearing towards sunset after a cloudy day, particularly with a westerly wind in autumn, was noticed by many persons in London because the sense of protection which a cloudy sky at that time carried with it vanished at the time when it might have been most acceptable. The impression of the phenomena is confirmed by statistics of cloud at Kew Observatory, Richmond, which were put together by Capt. D. Brunt and are published in Professional Note, No. 1 (M.O. publication 232a).

INTER-RELATION OF WIND DIRECTION AND CLOUD AMOUNT AT RICHMOND.

ODDS AGAINST ONE FOR A CLEAR SKY FOR A GIVEN WIND DIRECTION.

Hour.	Calm.	N	NE	E	SE	S	SW	W	NW
				SPRING. (*March—May.*)					
10 h.	∞*	7	7	3	3	12	10	13	20
16 h.	—	13	8	3	5	19	28	18	19
22 h.	∞*	2	2	1	1	3	2	2	1
				SUMMER. (*June—August.*)					
10 h.	∞*	8	4	2	3	8	21	16	21
16 h.	—	11	4	2	5	11	41	32	23
22 h.	1	3	2	1	1	2	2	3	2
				AUTUMN. (*September—November.*)					
10 h.	9	7	7	5	5	13	9	5	8
16 h.	1	7	9	2	17	8	18	14	7
22 h.	1	2	3	2	3	3	3	2	2
				WINTER. (*December—February.*)					
10 h.	2	4	6	5	15	18	12	5	3
16 h.	—	6	6	6	10	41	15	9	5
22 h.	∞*	2	3	4	4	11	4	2	1

* One observation only.

Capt. Brunt refers to this chapter as an explanation of the phenomenon, thus associating the evaporation of the cloud with the loss of heat by radiation. The explanation may be the true one, but it is proper to remark that the phenomena of the formation of clouds by eddy-motion referred to already in this chapter (p. 235), may furnish equally well a satisfactory explanation. The intensity of the eddy-motion under a steady wind diminishes in the evening in consequence of the gradual cooling of the surface by radiation to the sky. That result is familiar to us in the diurnal variation of wind velocity. It may be that as evening approaches the eddy-motion is not sufficiently intense to carry the surface air far enough upward to cause condensation.

In so far as radiation from the cloud occurs it would, of course. tend to cause descent of air as indicated in this chapter, and it is possible that both causes may concur to produce the actual result.

CHAPTER IX

THE LIFE HISTORY OF SURFACE AIR CURRENTS

RELATION OF AIR CURRENTS TO BAROMETRIC MINIMA—TRAJECTORIES OF AIR

WE are now in a position to turn our attention again to the various recognised forms of barometric distribution and consider the details of the weather associated therewith, bearing in mind the object of accounting for the various phenomena upon dynamical or physical principles. For this part of the subject we shall depend mainly upon the work represented by "The Life History of Surface Air Currents," a publication of the Meteorological Office issued in 1906.[1] That work began with a careful examination of the flow of air along the surface of the earth as determined by observations of wind. From the fact that a synchronous chart showing a well-developed cyclone indicates a series of isobars surrounding a centre and a series of winds more or less tangential to the isobars, but with some incurvature or inclination towards the side of the low pressure, it had come to be an accepted principle in meteorology that the line of flow of air along the earth's surface was represented by a double spiral in the shape of a reversed S. Curving spirally outward from a high pressure area which was regarded as the region of descent, the air was supposed to travel round a considerable portion of an anticyclone, always turning to the right, and presently to become involved in a cyclonic circulation. After more or less complete circumnavigation of the "low" centre in a spiral with a left turn, it was supposed to lose itself somewhere near the centre of the cyclonic

[1] We make frequent references to this work, and hereafter it will be sufficient if we refer to it as "The Life History."

area in a rising current, fed by the convergence of the air in spirals, and forming cloud and rain. This mental picture of the course of events taking place in a cyclone was elicited by supposing that the state of things shown on a synchronous chart was persistent in the sense that the actual paths of air with reference to the centre were the spirals that can be traced upon the chart by forming lines of wind arrows, head to tail, over the map. It leaves out of account the fact that the centre of low pressure is itself moving, and that sometimes it moves at least as fast as the fastest of its surface winds. It will readily be seen, when one takes account of the movement of the centre, that a wind which seems on a synoptic chart to be making for a point 100 miles in front of the centre may find itself actually at the centre when the time comes for it to cross the path; and on the other hand a wind that seems on the chart to be directed straight for the centre may equally miss it by 100 miles. An example of the difference between the suggested spiral paths of air and the actual paths on the map is given in Figs. 94 and 95, taken from "The Life History." Fig. 94 is an isochronous chart of the Atlantic for November 15, 1882, showing "highs" and "lows" connected by the S-shaped curves of instantaneous motion printed in red. Fig. 95 shows the actual paths of the air over the region on the day of the chart and the two days on either side of it. There is very little similarity between the actual paths and the S-shaped curves.

The slower the motion of the centre the more does the path that suggests itself on the synoptic chart become realised as the actual path of the air. A very good case in point is given by the charts of Fig. 96, which represent a persistent anticyclone over the Iberian peninsula. Round this anticyclone, according to all the evidence we could collect, a current of air travelled on February 19 to 22, 1903, and carried African dust to fall as red or earthy rain in our islands where the warm current from the south was pushed upward by a colder current that crept alongside after traversing the ocean from the west, as

1882 November 15

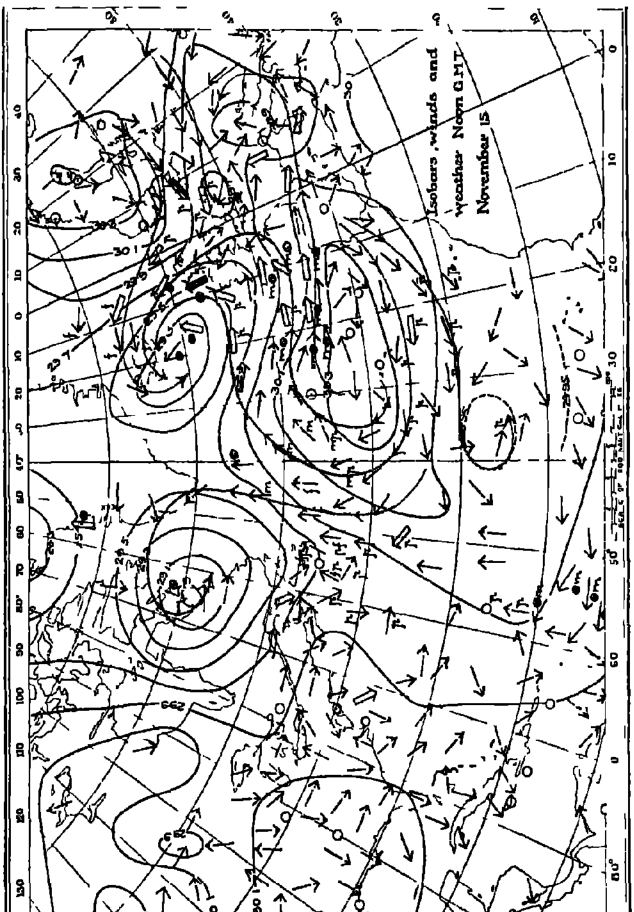


FIG. 94.—The Instantaneous Stream Lines of Air between the High Pressure and Low Pressure Areas shown on the Chart for November 15 are shown by Spiral Curves in Red. From "The Life History of Surface Air Currents."

Trajectories of Air over the North Atlantic.
1882. November 13 to 17.

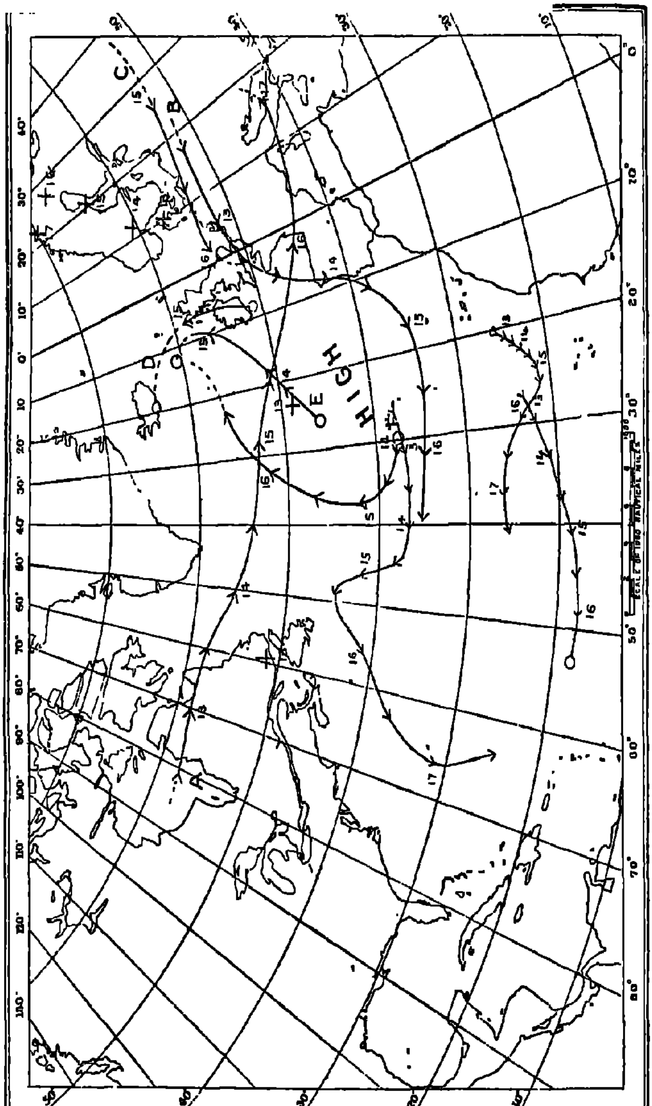
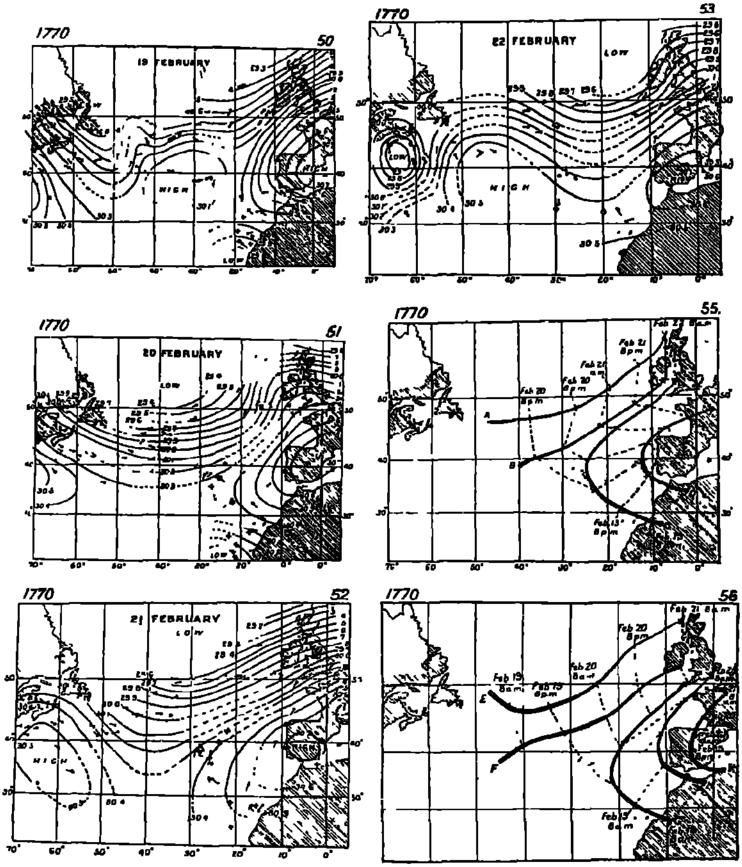


FIG. 95.—The actual Paths of Air as shown by the Trajectories are to be contrasted with the Instantaneous Stream Lines shown in red in Fig. 91. From "The Life History of Surface Air Currents," with additions.

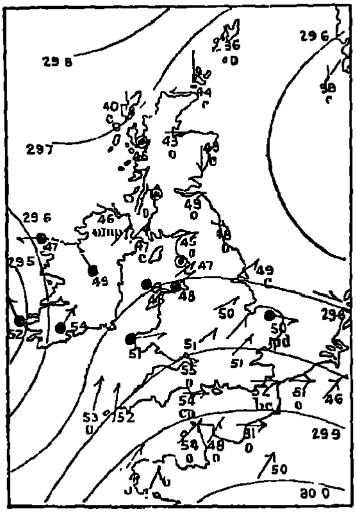


Persistence of Anticyclone Mill and Lempfert QJ 04.

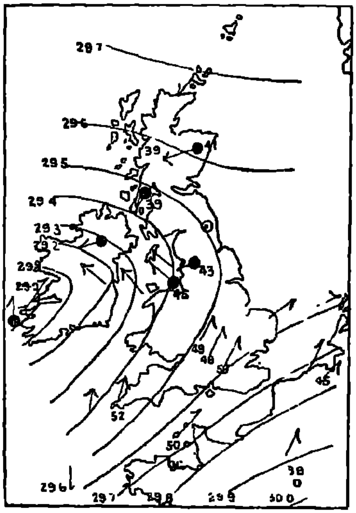
FIG. 96.—Charts of Isobars over the Atlantic for February 19 to 22, 1903, numbered 1770, 50 to 53, with Trajectories of Air for the same period, numbered 1770, 55 to 56.

Nos. 55 to 56 show Trajectories of Air carrying Dust from Africa round a persistent Anticyclone over the Spanish Peninsula, February 19 to 22, 1903.

1901. November 11, 6 p.m.



1901 November 12, 4 a.m.



1901. November 12, 8 a.m.

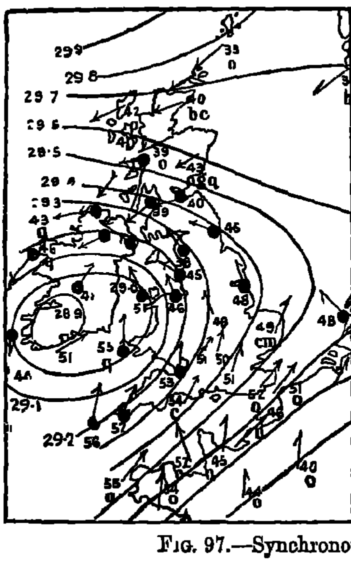
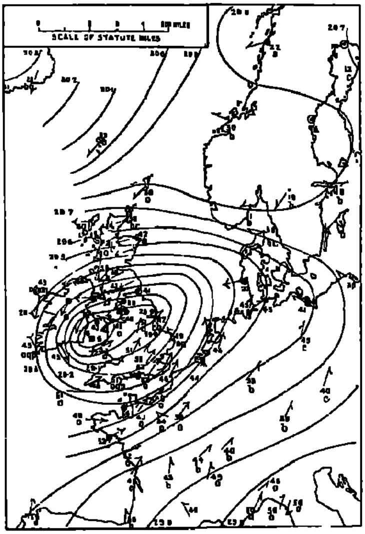
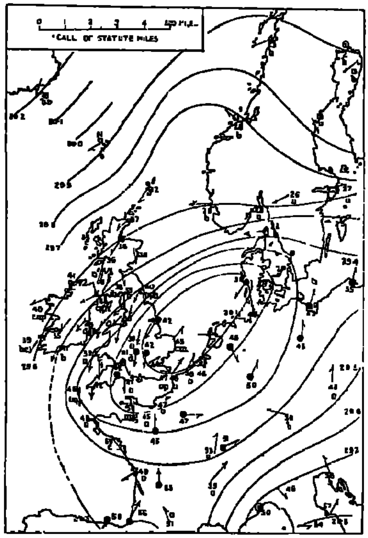


Fig. 97.—Synchronous Charts of the Slow

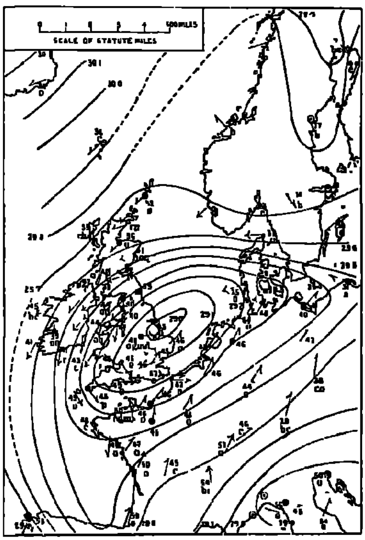
1901. November 12, 6 p.m.



1901 November 13, 8 a.m.



1901. November 13, 6 p.m.



Travelling Depression of November 11 to 13, 1901.

shown by the "trajectories" or actual paths of the air in the last two of the six charts of Fig. 96.[1]

Possibly gradual incurvature from all sides may take place in the case of tropical hurricanes, which move slowly compared with the wind that occurs with them; the order of relative magnitude may be taken as ten miles an hour for the motion of the centre as compared with 100 miles an hour for the motion of the hurricane wind. But observations upon such a point are not very numerous; observations of any sort during a hurricane are indeed specially difficult, and a good deal of our knowledge about them must necessarily be by inference. With the milder visitations of these islands we are in a better position for examining what actually takes place with regard to the motion of air.

With this object in view, Mr. R. G. K. Lempfert and I traced out the actual motion of air along the surface by constructing hourly maps for a number of special cases, some of which I will now refer to. Our plan was, by using hourly maps, to trace the actual paths of air step by step and examine the progress of the air as compared with the progress of the centre of the depression. We called the actual paths of the air as traced on the maps "trajectories of air," and I will first call attention to the maps and trajectories representing the paths of air associated with the very rainy depression of November 11 to 13, 1901. The minimum of pressure moved only slowly; the winds reached fifty-nine miles per hour, but the depression travelled about seventeen miles per hour; hence in this case we had conditions, as regards the relative proportion of speed of the wind to the speed of the centre, intermediate between those of a tropical hurricane and those of the fast-travelling circular storms which are not uncommon in these islands.

RAINY SLOW-MOVING DEPRESSION OF NOVEMBER, 1901

The six synchronous charts of Fig. 97 show some of the hourly maps, and charts A, B, C of Fig. 98 show the trajectories.

[1] Mill and Lempfert, "Quarterly Journal, Roy. Met. Soc.," Vol. 30, p. 57, 1904.

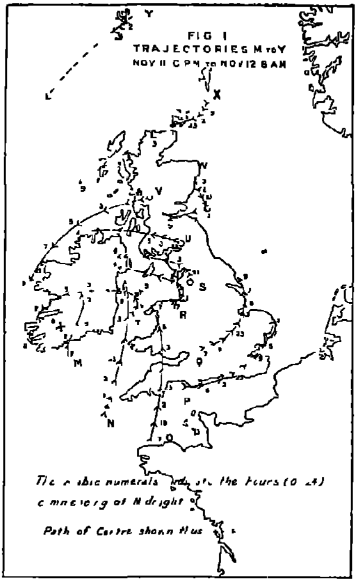


Fig. 98A.—Trajectories of Air, November 11 to 13, 1901.

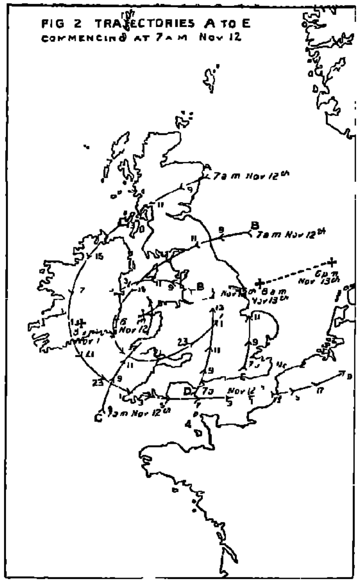


Fig. 98B.—Trajectories of Air, November 11 to 13, 1901.

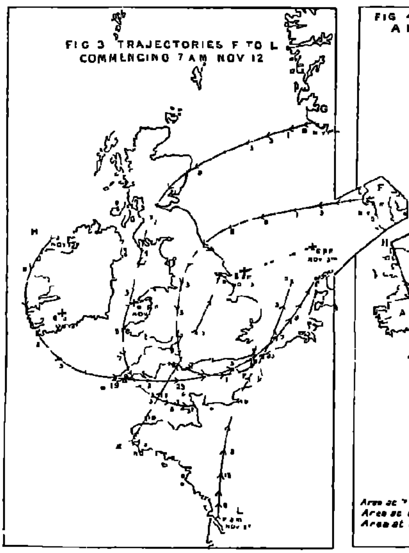


Fig. 98C.—Trajectories of Air, November 11 to 13, 1901.

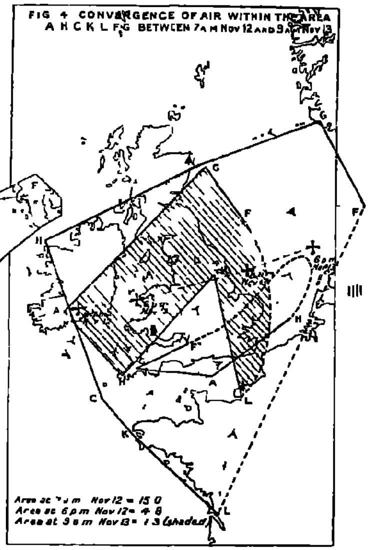


Fig 98D.—Diagram illustrating the Convergence of Air during the Passage of the Depression of November 11 to 13, 1901.

It will be noticed with regard to the latter that whereas all the air that approaches the centre directly from the south goes straight to the middle region and is lost, probably in an upward current, no single trajectory directed from any other quarter arrives at a termination in the central region without first turning round the rear and approaching from the south. This suggests that all the air which went upwards and caused rain in accordance with the principle of convergence referred to on p. 210, was that brought by the southerly winds, and that the function of the easterly or north-easterly winds to the north of the path of the centre was to form a barrier over which the southerly current could rise. Chart D of Fig. 98 shows the great convergence of air in this case which must have been associated with the great rainfall represented by isohyetal lines in Fig. 99. Along a strip of country on the north side of the path as much as four inches of rain fell in the course of the four days.

1901. November 11 to 13.

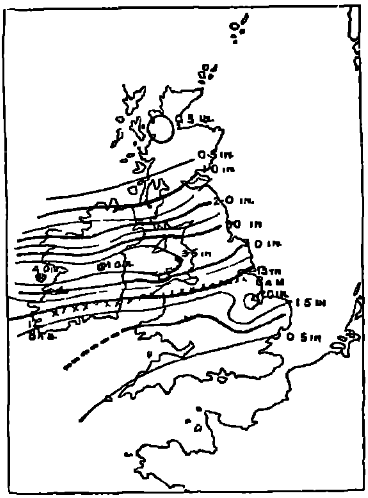


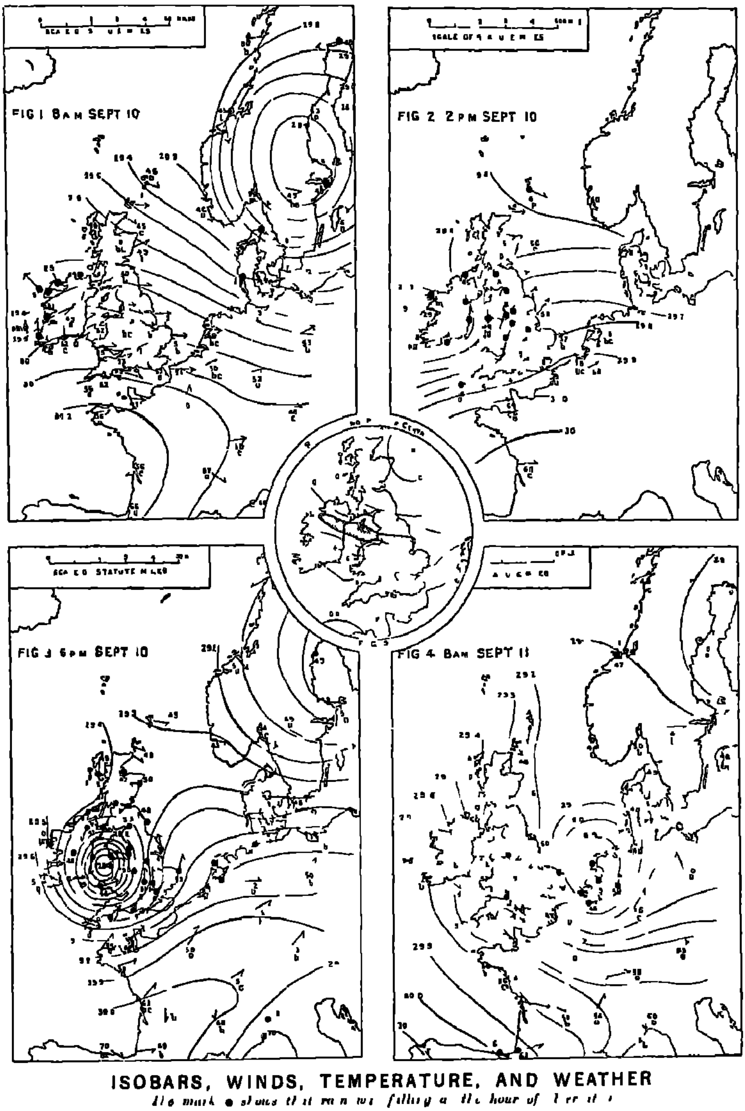
Fig. 99.—Distribution of Rainfall.

FAST-TRAVELLING DEPRESSIONS

The trajectories in the case of November 11 to 13 may be contrasted with those of the fast-travelling circular storm of September 10 and 11, 1903, which is represented in Fig. 100. The rain due to this depression, shown in the small central chart of the figure, fell in a position very similar to that affected in the previous case, but it reached only 1·5 inch, or less than half that of the slow-travelling storm.

In this case the air in all trajectories as shown in Fig. 101

CIRCULAR STORM OF SEPTEMBER 10-11, 1903



ISOBARS, WINDS, TEMPERATURE, AND WEATHER

The mark ● shows that rain was falling at the hour of [illegible]

FIG. 100

1903. September 10—11.

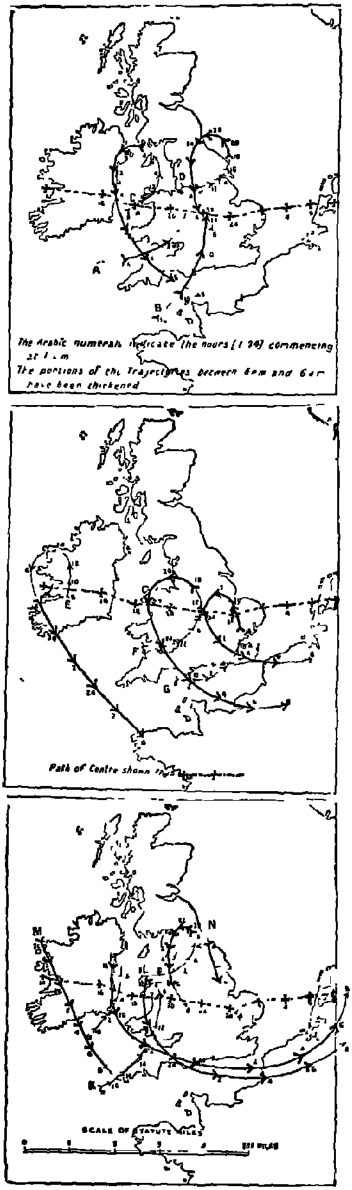


FIG. 101.—Trajectories of Air.

approaches the centre from the south-west, not directly from the south, and many of the trajectories are seen to form loops. The motion of the air becomes north and south when the path of the centre is reached in the course of the trajectory. It is not quite certain that the return portions of these loops are formed of the same air as the entering portions. A close examination shows that there is a good deal of convergence in the region near the centre, and it is uncertain whether or not there is descent of air near the turning points of the trajectories.

These two examples furnish a sufficient indication of what happens to the air in the central regions of the typical depressions which visit our islands. The difference of rainfall between the slow traveller of November 11 to 13, 1901, and the fast traveller of September 10 and 11, 1903, is characteristic. It is, perhaps, to the difference of character that the

difference of rainfall is due. It may be that so long as the supply of rain keeps up, the intensity of the depression can be maintained, otherwise it must either travel rapidly or fill up. The circumstances which favour rapidity of travel are still obscure. We shall bring some further considerations forward in a separate chapter on the motion of depressions and isallobaric charts.

KINEMATOGRAPHIC REPRESENTATION

The consecutive relation to the isobars of the course of the air along the earth's surface in a travelling depression is represented very effectively by setting a series of hourly maps each with its own isobars and portions of the trajectories in a zoetropic apparatus, which gives intermittent vision through a series of slits in a revolving drum. An apparatus of this kind, representing the passage of the air in different parts of the cyclonic depressions, discussed in "The Life History," was made for exhibition at the Meteorological Office on March 31, 1905. The apparatus was subsequently put into more permanent form in 1908 and exhibited at the Royal Society in that year, and it was described at the meeting of the British Association in Dublin. It is very instructive as showing how, according to the observations available, the different parts of cyclonic areas are fed with air from regions external to the depression. The original apparatus is now on exhibition in the museum of the Meteorological Office, and a duplicate in the Science Museum, London.

DISTRIBUTION OF TEMPERATURE AND WEATHER

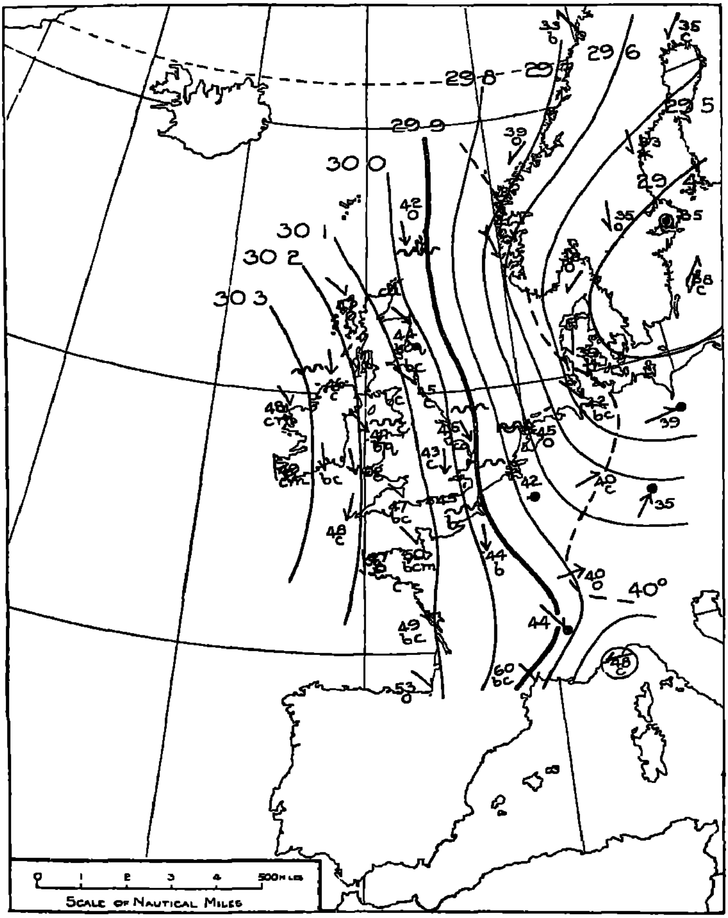
Let us now proceed to consider some details of the distribution of the other meteorological elements in travelling depressions.

I have at this stage little further to add to what I have written in respect of the distribution of temperature in synchronous charts in Chapter V., except to ask the reader to study again the chart of January 28, 1910 (Fig. 51), and the isothermal lines given in other illustrations, in connection with

the various causes of change of temperature enumerated in the preceding chapter. I will also give an illustration from two very similar distributions of pressure with notably different temperatures of the difficulty of dealing with temperature except upon the basis of long experience in the use of weather charts. Figs. 102 and 103 represent the charts for April 8 and 16, 1903. Notice that the temperature distribution of April 16 is about 10° colder in spite of a week's advance towards the summer solstice at a time of the year of rapid change.

We have already seen (p. 135) that the distribution of cloud and rainfall, as represented by Abercromby and accepted by meteorologists generally, gives regions of cloud and rainfall roughly represented by the outside closed isobar of the depression and an inner isobar respectively. The chart of distribution of pressure at 7 a.m. in the Daily Weather Report was accompanied by a second chart on the same scale showing temperatures by figures and isothermal lines and weather by letters of the Beaufort notation. The fact that rain was falling at the particular time of observation is indicated in the pressure map by marking a black dot at the position of the observing station. The position of these rain points with reference to the centre of the depression offers an interesting subject of study. We seldom get any large area of rainfall, but as the maps are for a single epoch we can only form a general idea of the distribution by combining together the information of many maps. In the course of the investigation of "The Life History" we wished to represent the motion of air and the distribution of weather with regard to the centre for certain of the cases therein considered, and for this purpose diagrams on the same scale as the trajectory maps were prepared referring the weather symbols on all the hourly or two-hourly maps to the centre of the depression. A diagram constructed in this way gives a definite conspectus of the weather in all directions round the centre for the particular case under review. The diagrams for the slow-travelling depression of November 11 to 13, 1901

1903. April 8, 8 a.m.



CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
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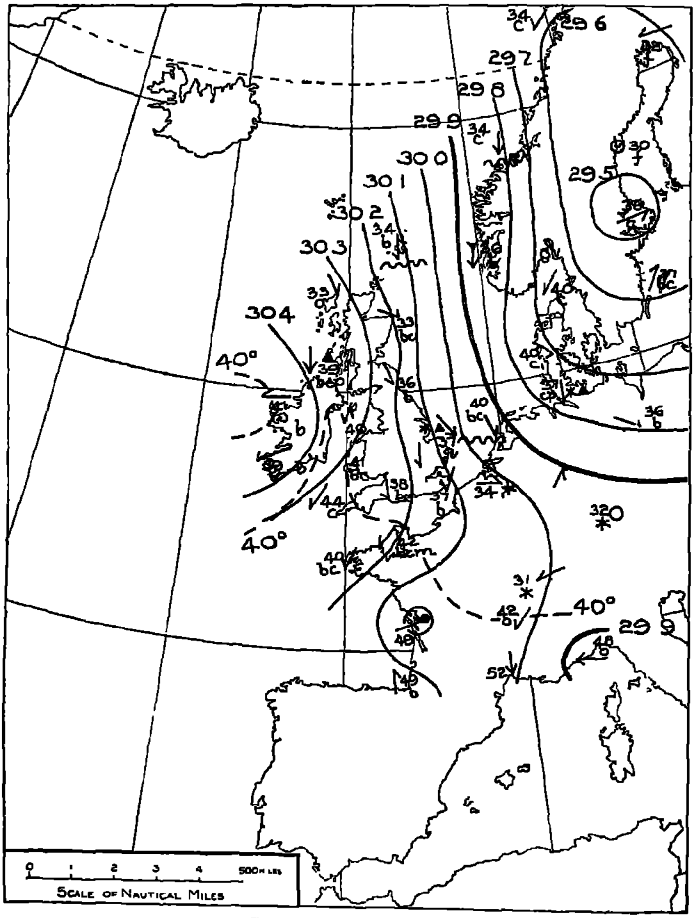
29·5	999·0	29·9	1012·5	30·2	1022·7
29·6	1002·4	30·0	1015·9	30·3	1026·1
29·7	1005·7				

The bolder dotted line is the isotherm of 40° F., 277·4 t.
It is much further east than the corresponding line in Fig. 103.

FIG. 102.—Barometric Distribution similar to that of Fig. 103, with Weather about 10° warmer.

1903. April 16, 8 a.m.



CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
29·5	999·0	29·9	1012·5	30 2	1022·7
29·6	1002·4	30·0	1015·9	30 3	1026·1
29·7	1005·7	30·1	1019·3	30·4	1029 4
29·8	1009·1				

The bolder dotted line is the isotherm of 40° F., 277·4 t. It is much further west than the corresponding line in Fig. 102.

FIG. 103.—Barometric Distribution similar to Fig. 102, with Weather about 10° colder.

(Fig. 97), and for two fast-travelling storms, March 24 and 25, 1902 (Life Hist.), and September 10 and 11, 1903 (Fig. 100), are reproduced in Figs. 104, 105, and 106. In these diagrams the centre of the depression is indicated by the crossing of the two thick lines at right angles, one representing the path of the centre and the other the trough line. The lines with arrows represent the hourly steps in the motion of the air *with reference to the centre*, that is to say, they indicate the way in which the air would appear to move to a person travelling with the centre or minimum. The black dots indicate positions in relation to the centre at which rain was noted on the hourly or two-hourly maps. The area of rainfall, excluding a few isolated points where the weather is marked *p*, that is to say, where there was or recently had been a shower, is shaded, and the shaded area may be taken to compare with the rain area of Abercromby's diagram. It will be seen that an area round the centre, roughly represented by the line of an isobar, is not a good representation of the rainy area as indicated by these three diagrams. We have, instead, for the two fast-moving depressions a roughly rectangular area with its sides at 45° to the line of motion and line of trough, cutting across the depression so as to give very little rain area behind the actual centre on the right rear, but a good deal before the centre in the right front. If we could regard these two cases as typical we might say, since the line of trough is the one at right angles to the path through the centre, it would be raining with the falling barometer in the right front and in the left front. In the rear the rain would continue with the rising barometer on the left, but not on the right.

With the slow-moving depression also most of the rainfall is on the left of the path (Fig. 105); there is comparatively little on the right. The rain area is more elongated and more nearly parallel to the line of the path.

A notable feature of the diagram of the slow-moving depression is the isolated and elongated rain area which crosses the trough line. That is probably connected with certain

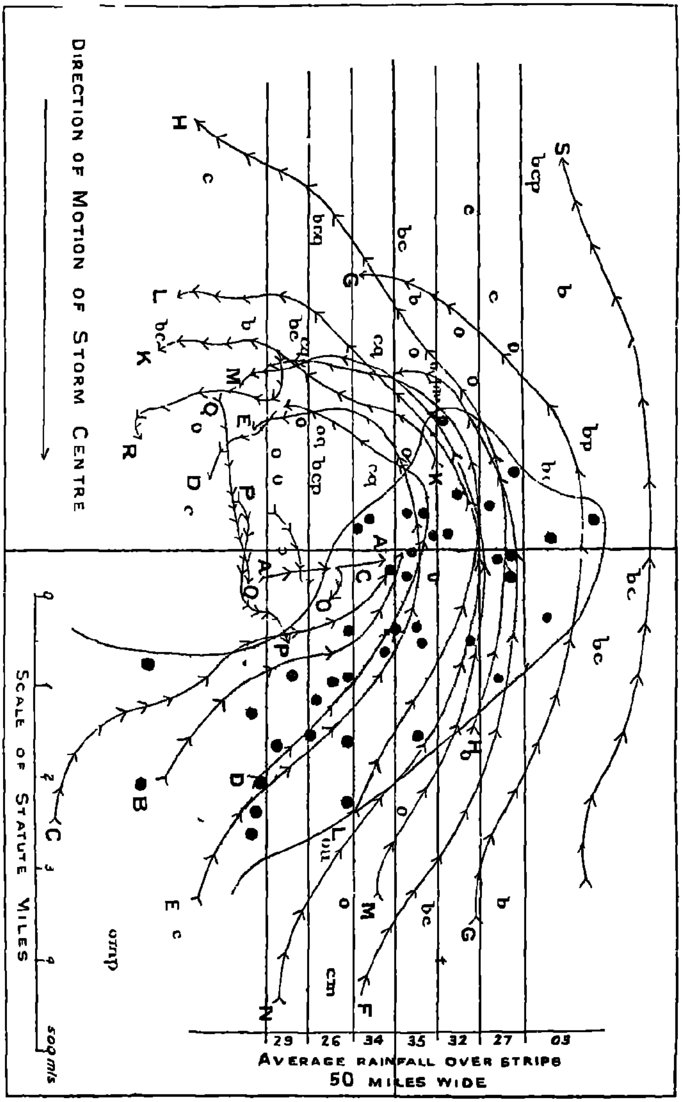


FIG 104.—Motion of Air and Distribution of Weather and Rainfall relative to the Centre of Lowest Pressure in the Circular Storm of March 24—25, 1902.

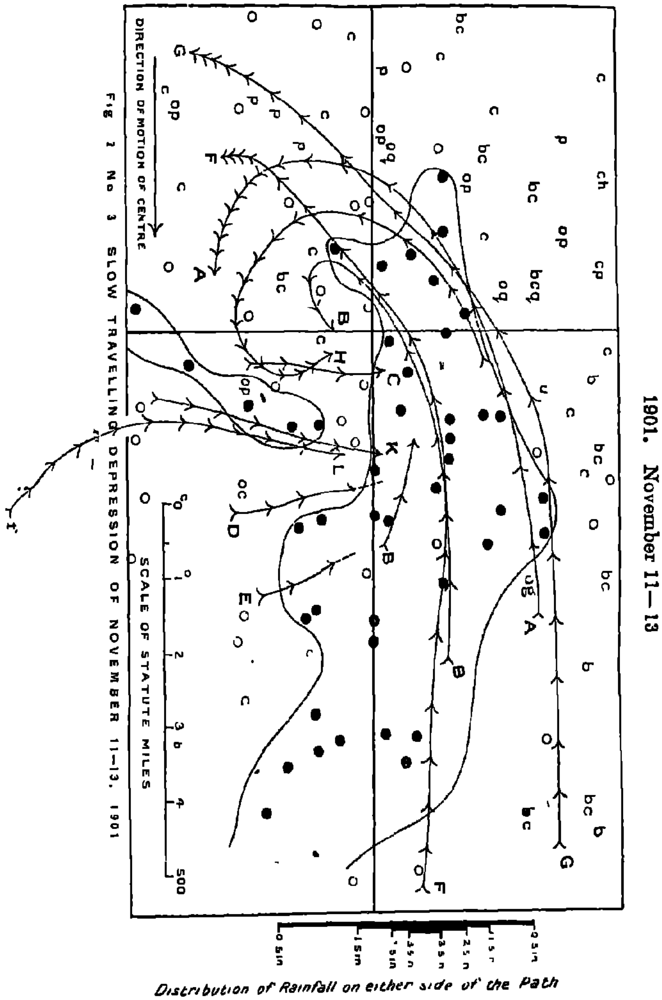


FIG. 105.—Motion of Air and Distribution of Weather and Rainfall relative to the Centre of Lowest Pressure in the Slow-travelling Storm of November 11—13, 1901.

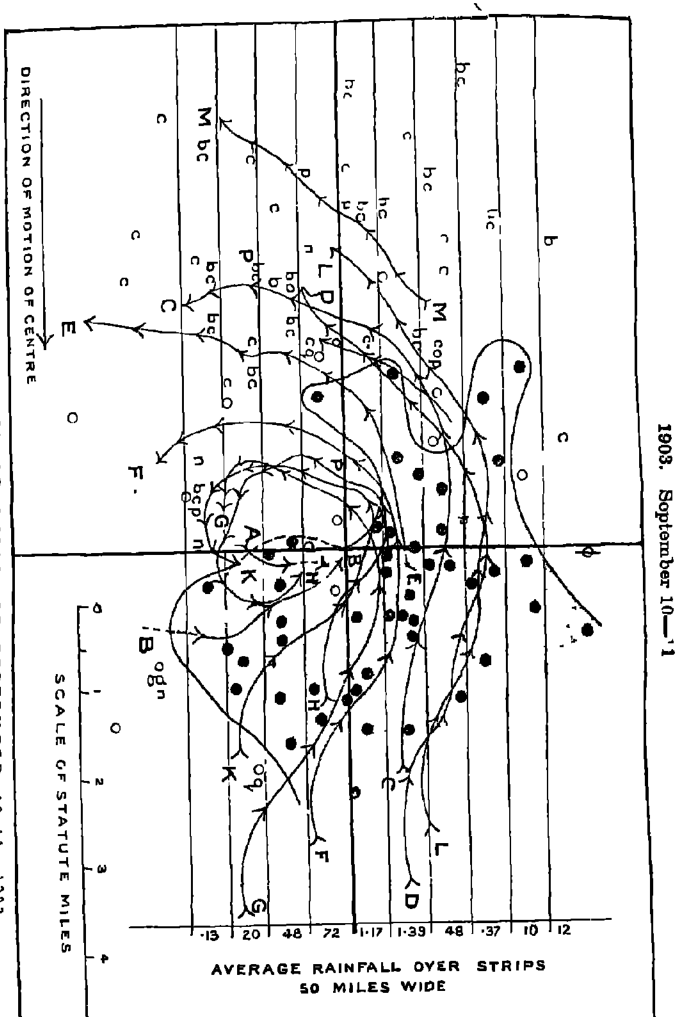


FIG. 106.—Motion of Air and Distribution of Weather and Rainfall relative to the Centre of Lowest Pressure in the Fast-travelling Circular Storm of September 10—11, 1903.

curious phenomena of the trough, with which we shall deal presently.[1]

The distribution of cloud or clear sky outside the rain area is indicated by the letters *o*, *c*, *bc*, and *b*. If we consider *b* and *bc* as representing fine weather and the others as cloudy, we could draw a line enclosing the cloud area. Such lines would agree, roughly speaking, with the boundary of cloud indicated by Abercromby, but in some other cases it may be noticed that it is fine in the inner region of a depression. February 26, 1910, furnishes a case in point. A reference to the map (Fig. 107) shows that the isobar for 29·3 encloses regions which are marked with such varieties of weather as clear sky, sky one-quarter clouded, overcast, rain, and snow. In London, with all the pressure associations of the worst weather, it was noted as a brilliantly fine day. The distribution of rainfall on February 12, 1904, 6 p.m. (Fig. 108), is also peculiar. The lettering shows that there is a strip of blue sky between two rain areas in the front of the depression.

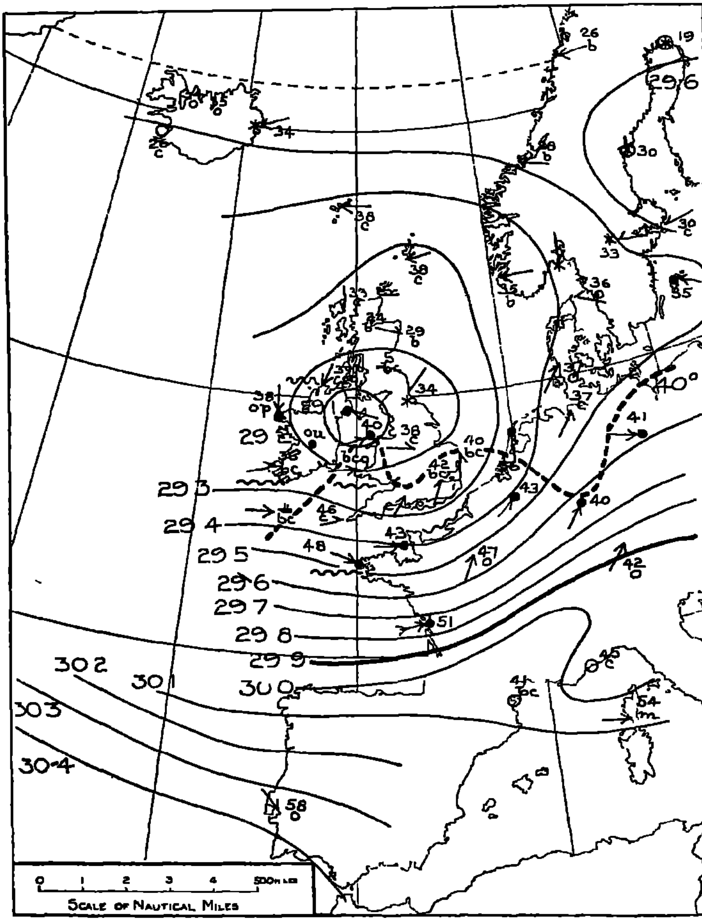
The distribution of clouds of different kinds with reference to depressions is a very large subject, which is treated to a certain extent in the sections quoted from Abercromby, Chapter V. Its systematic study offers an opportunity of great practical importance to the local observer, and should become in time a definite department of nature study in rural schools. We have already referred in Chapter II. to the principle of classification of cloud forms introduced by the publication of the International Cloud Atlas. The reader who is interested in the details of this subject may be referred to Mr. A. W. Clayden's "Cloud Studies" (John Murray) or Mr. G. A. Clarke's "Clouds" (Constable & Co.).

RAIN IN CYCLONIC DEPRESSIONS

In dealing with the application of the general ideas concerning the production of rain to the special circumstances of particular cyclonic depressions, let me refer to the diagram

[1] A chart of the distribution of cloud and rainfall for a depression of November 12 to 13, 1915, is given by Lempfert and Geddes, "Q. J. Roy. Met. Soc.," Vol. 43, p. 22, 1917; "The Weather Map," p. 54.

1910. February 26, 7 a.m.



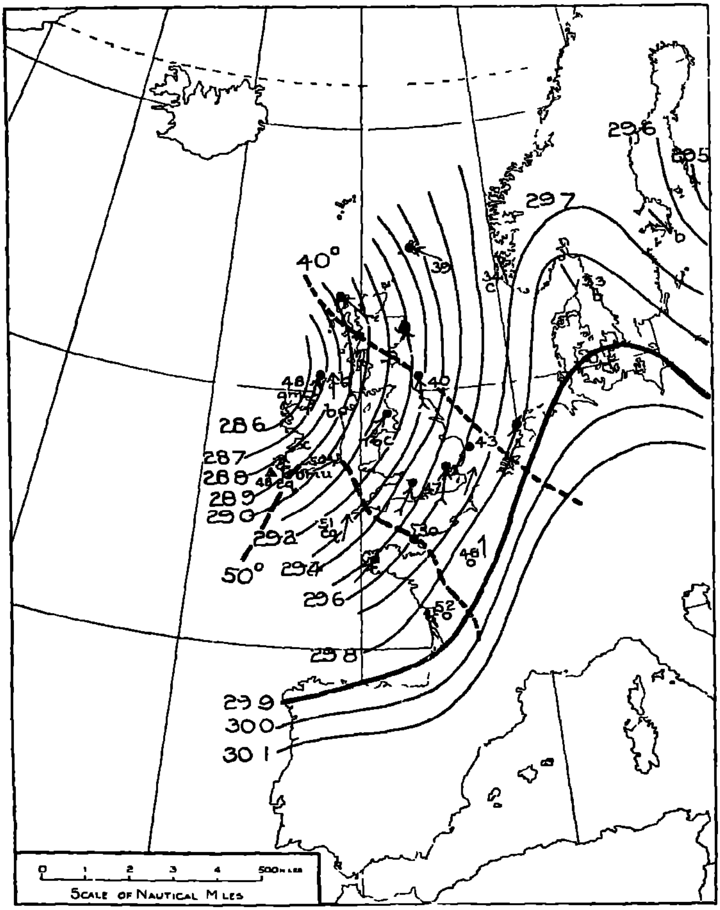
CONVERSION TABLE.

In.		Mb.	In.		Mb.	In.		Mb.
29·1	.	985·4	29·6	.	1002·4	30·1	.	1019·3
29·2	.	988·8	29·7	.	1005·7	30·2	.	1022·7
29 3	.	992 2	29·8	.	1009·1	30·3	.	1026·1
29·4	.	995·6	29·9	.	1012·5	30·4	.	1029·4
29·5	.	999·0	30·0	.	1015·9			

The bold dotted line is the isotherm for 40° F., 277·4 t.

FIG. 107.—Fine Weather within the Central Region of a Cyclonic Depression shown by the letters *b*, *bc*, within the Isobar of 29·3 inches.

1904. February 12, 6 p.m.



Conversion Table.

In.	Mb.	In.	Mb.	In.	Mb.
28·6	968 5	29 2	988·8	29·7	1005·7
28·7	971·9	29·3	992 2	29·8	1009·1
28·8	975·3	29·4	995 6	29·9	1012·5
28·9	978·6	29·5	999·0	30·0	1015 9
29·0	982·0	29·6	1002·4	30·1	1019·3
29·1	985·4				

The bold dotted lines show isotherms for the 40° F., 277 4 t., and 50° F., 283 t.

Fig 108.—Fine Weather shown by the letters *b*, *bc*, on the two sides of the Irish Sea between two Rain Areas in the front of an Advancing Depression.

(Fig. 105) representing the distribution of weather with reference to the centre in the case of the rainy depression of November 11 to 13, 1901. In addition to the large rainy area in the front of the depression, there is a detached region of rain enclosed in a line drawn round five black dots which mark the positions where rain was falling. These five dots lie in a line which is nearly straight, but gives some indication of curving inwards as the centre is approached. It crosses the trough line and keeps near to it. If the line of dots were continued up to the centre it might be regarded as a distorted line of trough. Note also that this region of rainfall is near the western boundary of the region of southerly winds. Further to the west we find certain examples of winds which are travelling eastward faster than the centre of the depression; thus the westerly wind may be regarded as running into the southerly wind, and the rainfall may perhaps be attributed to the westerly wind passing under the southerly wind at the surface. The trajectory lines on the diagram indicate that, in one part, the current coming from the west turned northward, and it is scarcely reasonable to dispose of the air in any other way, because a continued motion faster than the centre of the depression would result in the depression being left behind. It would thus appear that the arrest of the eastward velocity in excess of the motion of the centre was accounted for by the undercutting of the warm southerly wind by a colder wind from the west and the subsequent diversion of the lower stratum towards the centre.

We have in this diagram a significant illustration of two of the different sets of conditions in which rain can be formed by the convergence of stream lines: first, the passage of the southerly current of moist air over the barrier of cold easterly wind northward of the centre; and, secondly, the overwhelming of the ground on the western flank of the southerly current by a flood, or perhaps a flush of cold air, coming from the west. The supply of moisture in both cases is provided by

the southerly current. In the first case the current meets with an obstacle in front which it surmounts, and thus provides the abundant rainfall of the left front of the depression. In the second case the warm air supply is attacked on the western side by air, which pushes underneath it and causes a narrow band of rainfall.[1] In the particular instance represented by the diagram the westerly wind appears to have come round from the north, but this is not a matter of importance. The point to be noted is that it is colder than the southerly air which it replaces. The changes of temperature at Scilly from 56° at 8 a.m. in the southerly wind to 51° at 2 p.m. on November 12, at Portland from 55° at 2 p.m. to 51° at 6 p.m., and at Brest from 55° in a south-westerly wind at 8 a.m. to 49° at 6 p.m., indicate the amount of difference between the two currents.

AIR SUPPLY IN CYCLONIC DEPRESSIONS

If this representation of the conditions for the production of rain be a true one, the cyclonic depression comes to have a very different aspect from that which is usually accepted. The essential constituent is the southerly wind which forms the eastern flank of the cyclone; next we require a cold easterly current crossing the southerly wind at about the line of the path; and, thirdly, we require a wind which I will call a westerly one, because it is westerly when it invades the ground of the southerly current. Of these three currents at least two represent supplies of air from widely different quarters. The southerly wind is a warm moist wind, which comes from some distance to the south of the depression; the easterly wind is a dry cold wind, which may enter the depression from the south-east, east, or north-east. A westerly wind may come originally from the north, but the westerly wind that cuts under the southerly wind is a cold and relatively dry

[1] The reader should compare the positions of the two rainfall areas with the positions of the two V-shaped depressions shown in the chart for December 23, 1909 (Fig. 43, Chapter V.).

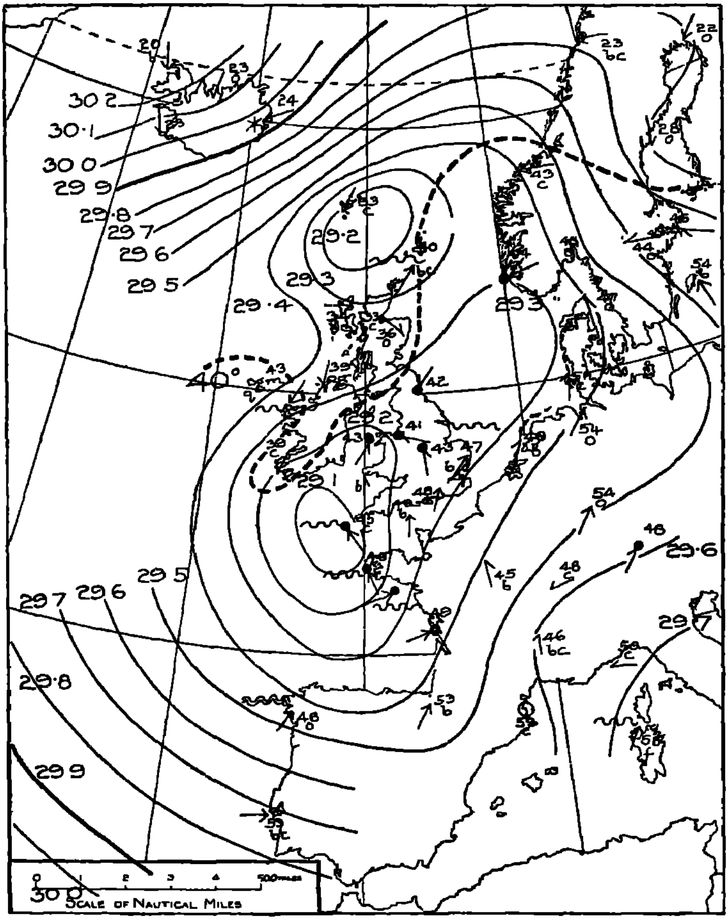
wind, coming from the north-west, possibly from the Atlantic; it may, however, come from the north or north-east, and bend round the rear of the depression.

A very good example of the separation of the areas of rainfall is given by the 7 a.m. map for Friday, April 15, 1910. The rainfall of the front is clearly distinguished from that of the trough (Fig. 109). The rainfall of the front is indicated by dots at Holyhead, Liverpool and Nottingham, whereas the rainfall of the trough is represented by the line of dots, Scilly, Brest, l'Orient and Rochefort. A very interesting example of the distribution of rainfall is given by the chart for March 10, 1910 (Fig. 110). All three types of rainfall are shown in separate areas. In the north we have an east and west line of front-rainfall, where a southerly wind crosses an easterly one, in the south there is general convergence, and in the west the cutting in of westerly winds to southerly winds with the usual varieties of weather from *b* to *p*.

These winds from different ultimate regions cross one another in the depression at finite angles and almost every depression shows large tracts covered by winds of nearly uniform direction succeeded by different winds which are also uniform over large areas. The juxtaposition on the map of these regions of winds of definite direction with a finite difference of angle between the directions of the regional winds, suggests the sudden transition from the one direction to the other as the changes pass over the map. The suggestion is quite well borne out by the anemograph records and, indeed, also by common observation.

The variations of the weather-cock are for the most part sudden shifts of wind, and a study of the anemograph records shows that there are frequently sudden transitions from a steady or nearly steady wind in one direction to an equally steady wind in a direction arrived at by veering through an angle of from four points or less to as much as eight points or even more. It is a matter of common observation, too, that these sudden veers of wind are attended with equally sudden

1910. April 15, 7 a.m.



Conversion Table.

In.	Mb.	In.	Mb.	In.	Mb.
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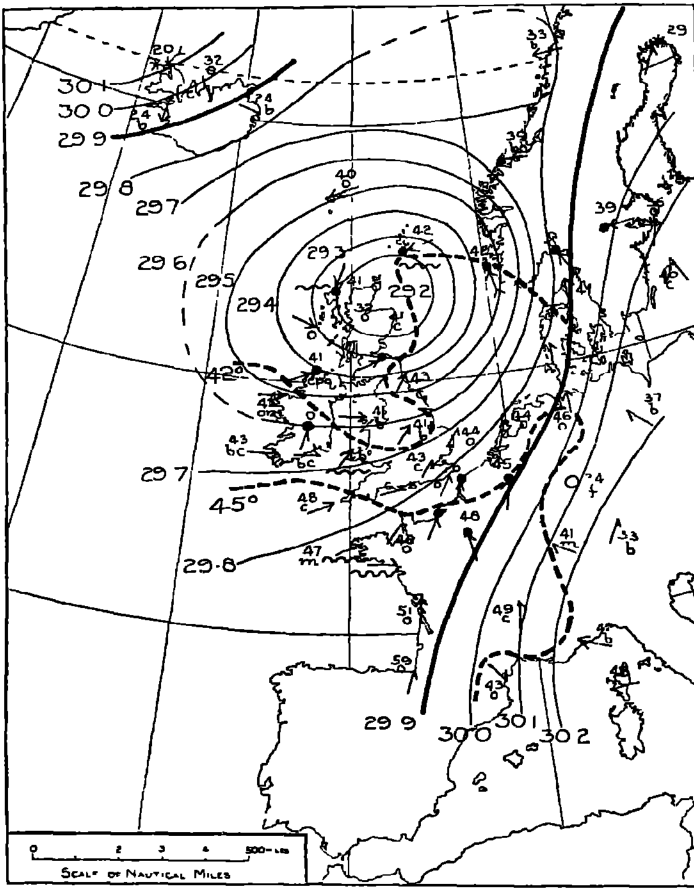
29 2	988 8	29 6	1002 4	30·0	1015·9
29·3	992 2	29·7	1005·7	30 1	1019·3
29·4	995·6	29·8	1009·1	30·2	1022·7

The bold dotted line is the isotherm for 40° F., 277·4 t.

Fig. 109 —Rain Lines in the North-Eastern and South-Eastern Regions of a Cyclonic Depression.

1910. March 10, 7 a.m.



Conversion Table.

In.	Mb.	In.	Mb.	In.	Mb.
29·2	988·8	29·6	1002·4	30·0	1015·9
29·3	992·2	29·7	1005·7	30·1	1019·3
29·4	995·6	29·8	1009·1	30·2	1022 7
29·5	999·0	29·9	1012·5		

The bold dotted lines are isotherms for 42° F., 278·6 t., and 45° F., 280·2 t.

Fig. 110.—Chart showing three different kinds of Rain Formation in a Cyclonic Depression:

1. Southerly Current over Easterly Current, Shetland to Sweden.
2. Convergence of the Southerly Current, Northern France.
3. Westerly Wind cutting under Southerly Wind, Ireland.

and permanent changes of temperature, from which we may certainly infer that the air supply is being drawn from a different locality. Not infrequently the transition from one air supply to another is accompanied by showers or other disturbance of the weather.

So far as I know, these sudden changes of wind direction with the accompanying phenomena of weather are confined to the north-west, south-west, and south-east quadrants of the depression; they are most frequent in the south-west quadrant between the trough and the path, most frequent indeed at the trough line itself where the westerly wind cuts into a southerly or south-westerly wind; but one can find examples of a south-wester cutting into a southerly wind and even of a northerly wind cutting into a north-wester (see the map for 7 a.m. Sunday, January 1, 1911). But I know of no example of a north-easterly wind cutting into a north wind, or an easterly wind cutting into a north-easter; cases of a south-easterly wind suddenly invading an easterly wind are perhaps doubtful.

The sudden transitions of wind are always in the direction of veering and of colder wind; the backing from a cold wind to a warm one does not present the same characteristics of suddenness and completeness; the backing may be rapid, but it is then irregular and has not the characteristic features of the steps observed in veering. Generally speaking, backing occurs when the wind is light and uncertain, but the veering here spoken of often takes place when winds are strong, sometimes when they are at their strongest.[1]

DIFFERENT TYPES OF DEPRESSION

While the sudden transition from one wind to another from a different direction is a marked characteristic, particularly of what may be called the south-western half of a depression, that is to say, the half of the depression which lies to the south-west of a diameter running north-west and south-east, and is often more marked the more intense the depression, such sudden changes are not universal. There are occasions

[1] The reader should compare with this account of the air-supply in cyclonic depressions that given by J. Bjerknes in "The Polar Front," Chapter X.

(probably the fast-travelling depressions of March 24 and 25, 1902, and September 10 and 11, 1903, would illustrate them) when the backing and veering of the wind is a gradual sequence, and this leads one to suppose that the convergence of winds, or of stream lines of air, producing rainfall is not always due to the crossing of currents at a finite angle, but may arise from the closing in of currents approaching the centre of a depression. That there is a general convergence of stream lines within the area of a depression is certain and it has been examined numerically in the examples referred to and represented by the diagrams. Chart "D" of Fig. 98 reproduced from "The Life History," shows how great was the general convergence in the depression of November 11 to 13, 1901, and the convergence for different parts of the depressions has been measured by finding the change in area, within two hours, of the boundary represented by circles when the centres are placed at the various points.

These differences and the convergences shown by them include the crossing of currents which we have already referred to, but in some cases we are entitled to conclude that there is also gradual approach of stream lines from nearly identical directions and consequent thickening of the surface layers and elevation of part of the air. Possibly it is convergence of this character which accounts for the more or less uniformly distributed rainfall in the right front and left rear of the depression, while the crossing of winds increases the rainfall of the left front and accounts for the heavy showers of the trough and the south-west quadrant of the depression.

REPRESENTATION OF A DEPRESSION

From this analysis of the causes of rainfall in different parts of a depression we may make a new representation of the constituent parts of a complete depression which will be useful for reference in future. It is given in Fig. 111. E, E is the easterly current forming the northern barrier of the depression. S, S to SE, SE the converging southerly current, and W, W

the invading westerly current. The positions of the areas of convergence due to the crossing of lines of flow or the approach of adjacent lines should be compared with the positions of the rain dots for March 10, 1910. (Fig. 110.)

The north-west quadrant is not filled up. It is the region where the air sometimes bends round from the east to the north-west and west, but the air supply for the westerly current is not always derived in that way.

The representation is exaggerated, but perhaps not more so

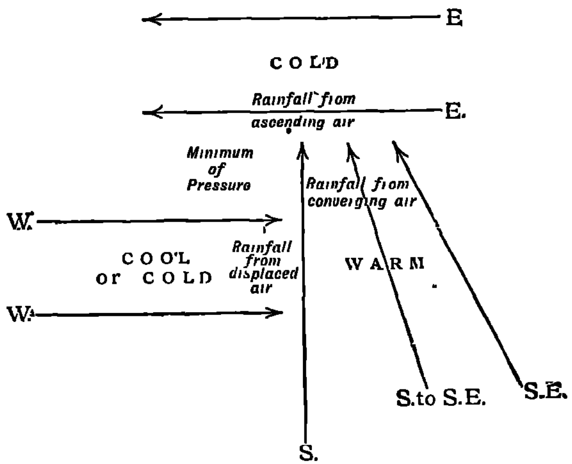
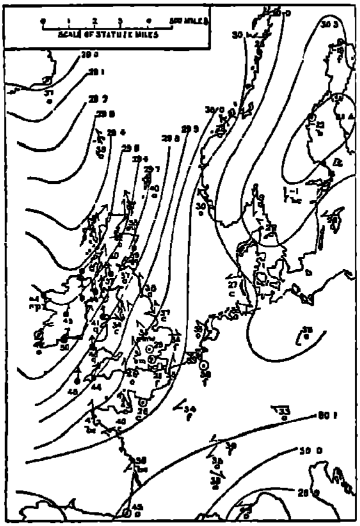


FIG. 111.—Diagram Representing the Constituent Parts of a Cyclonic Depression.

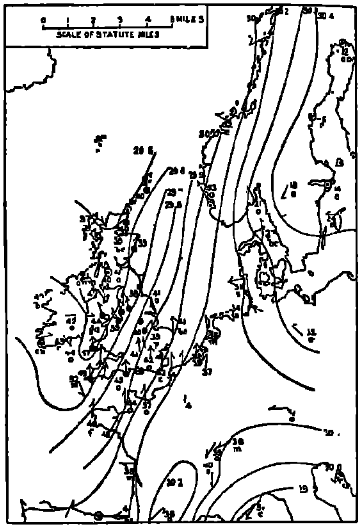
than the conventional representation of continuous circulations round a central minimum. Upon a synchronous chart the sudden veerings of wind are not generally so marked as those represented in the diagram, but the representation is a useful one to bear in mind.

Moreover, there is some confirmation of this mode of representation from a consideration of the trajectories of air over the Atlantic Ocean as given in "The Life History." It is there shown that a southerly wind generally keeps a very straight course, but is short-lived; its function, apparently,

1900. January 6, 8 a.m.



1900. January 6, 6 p.m.



1900. January 6, 9 p.m.

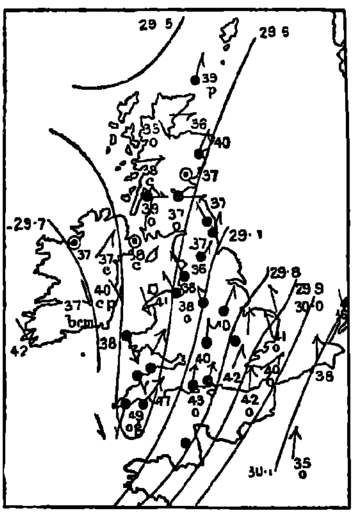
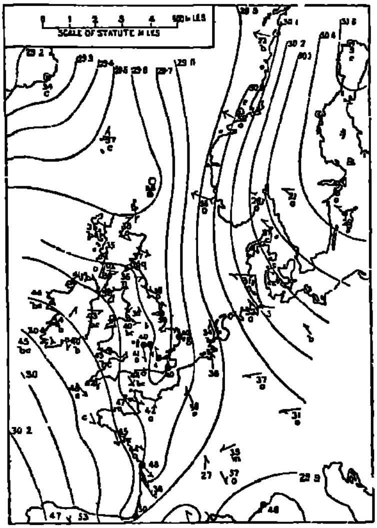
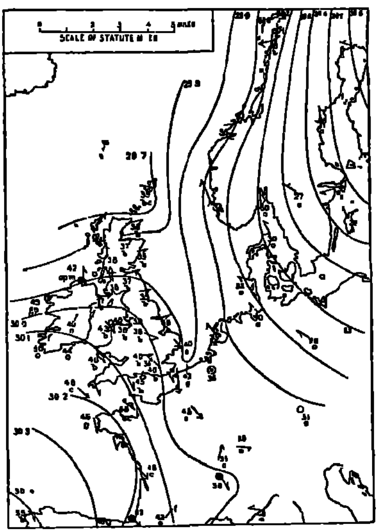


FIG. 112.—Charts illustrating the passage of a V-shaped

1900 January 7, 8 a m.



1900. January 7, 6 p m.



Depression or "Ligne de Grain," January 6 to 7, 1900.

is to be driven upwards either by its own convergence, or by meeting a body of cold air ahead, or by being invaded by cold air on its flank. It is precisely the kind of fate one would expect for warm air coming from southern regions laden with moisture. On the other hand, the cold air of the easterly current is very unpromising material out of which to make a rising current. It is, in all probability, a part of some anticyclonic supply from further north and is on its way southward cooling the surface as it goes, itself getting warmer and remaining in consequence a dry wind. Such a wind has all the qualifications for keeping along the surface until by travelling over warm sea in the rear of some low pressure area it becomes a warm southerly current and ready to ascend.

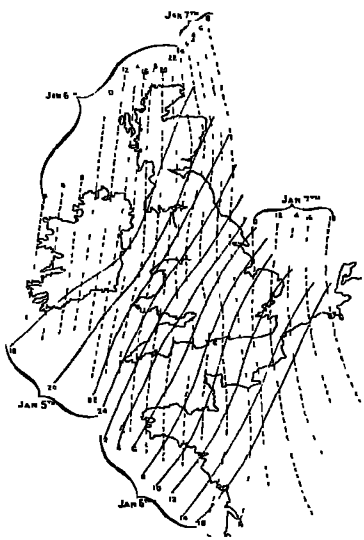
V-SHAPED DEPRESSIONS

We saw that there were two separate regions of rainfall for the depression of November 11 to 13, 1901, and that of these two regions one may be associated with rainfall caused by gradual convergence or by the easterly wind in front of the southerly one, and the other to the undercutting of the southerly wind by a cold westerly one. V-shaped depressions seem to afford notable examples of this second type of rainfall formation. In illustration of this we may point to the case of the V-shaped depression of January 6 and 7, 1900, dealt with by means of two-hourly maps in the work on surface air-currents. Fig. 112 represents a series of the maps, beginning with that for 8 a.m., January 6, and ending with that for 6 p.m., January 7. Fig. 113 represents the lines of advance of the trough, and Fig. 114 the motion of air and distribution of rainfall with reference to the line of trough. The charts and diagrams speak for themselves; the replacement of a southerly current by a northerly one is obvious, the disappearance of the southerly air near the trough, and the association of that event with the rainfall, equally so.

Another characteristic example of the distribution of rain

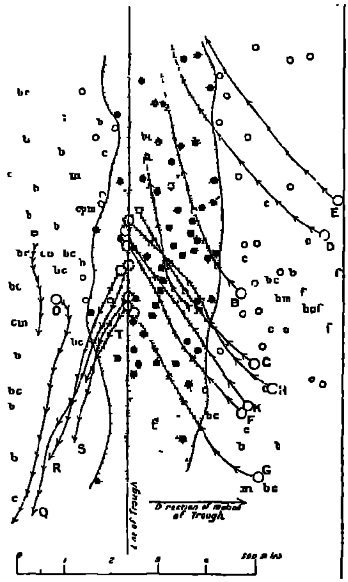
in a V-shaped development of a cyclonic depression is afforded by the map for 7 a.m. of June 24, 1910 (Fig. 115). The

V-shaped Depression, January 5 to 7, 1900.



The broken lines indicate the positions of the trough of lowest pressure. The continuous lines separate the region under the influence of the disturbance from the anticyclonic region in front of it. A station was regarded as coming under the influence of the disturbance when the wind velocity at it reached 10 miles per hour.

FIG. 113.—Position of Trough and Boundary of Storm.



The circles at the beginning or end of the trajectories indicate that the trajectories commenced or ended in a region of calm.

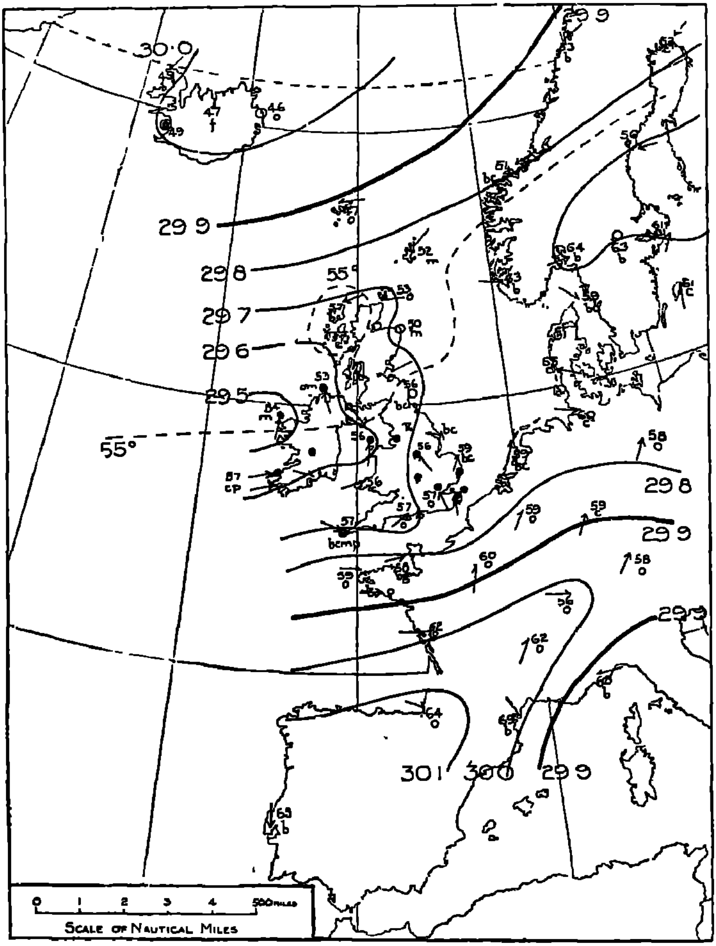
FIG. 114.—Motion of Air and Distribution of Weather and Rainfall relative to the Trough of lowest Pressure.

positions of the rain dots are a sufficient indication of the rain area.

PARALLEL ISOBARS AND RAIN LINES

Let us now consider another of the selected types of isobars, one which is noteworthy for irregularly distributed rainfall, namely, the case of parallel westerly isobars when we have to deal with a current of great width, covering a long stretch, from some point between south-west and north-west. (See

1910. June 24, 7 a.m.



Conversion Table.

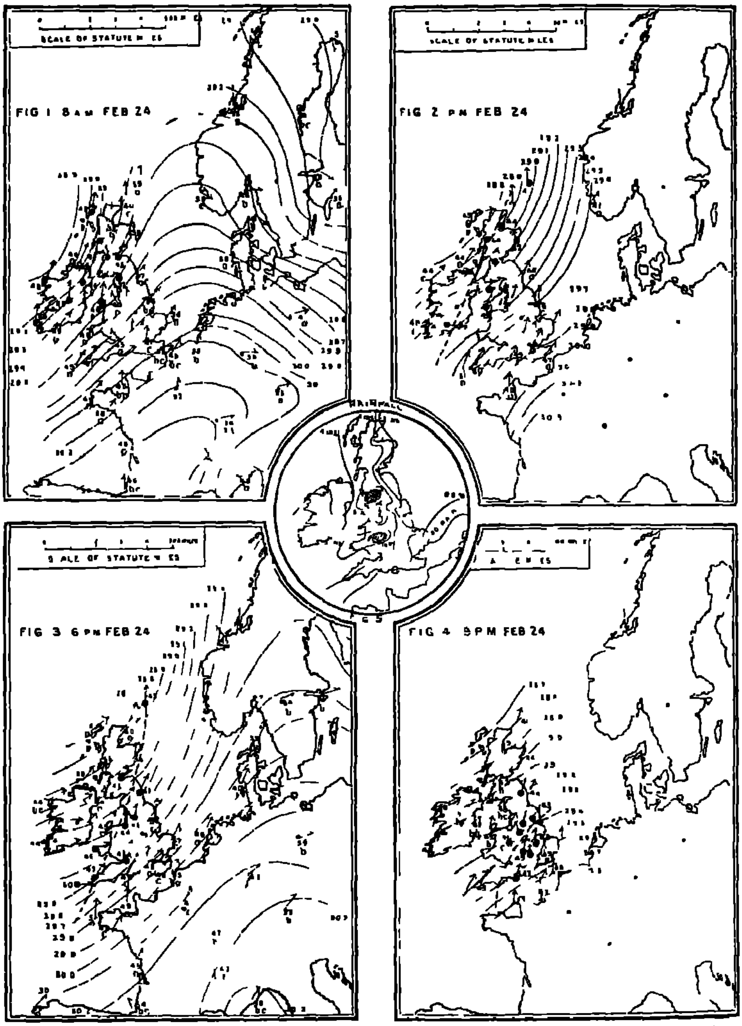
In.	Mb.	In.	Mb.	In.	Mb.
29·5	999·0	29·8	1009 1	30·0	1015·9
29·6	1002·4	29·9	1012·5	30·1	1019 3
29·7	1005·7				

The bolder dotted lines are the isotherms for 55° F., 285·8 t.

Fig. 115.—Chart showing the position of the Rain Area in a V-shaped Depression.

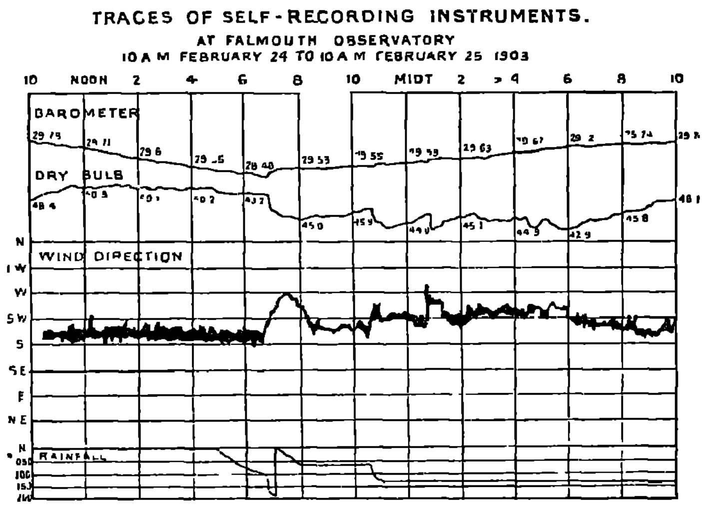
Fig. 37, Chap. V.) This case is very well illustrated by the sudden decrease in the force of the wind accompanied by a change in wind direction on February 24, 1903, which forms the subject of the eighth section of "The Life History." If we look at the map for 8 a.m., February 24 (Fig. 116), we find a regular system of south-westerly isobars over the British Isles forming apparently the south-eastern quadrant of a great cyclonic system with its centre somewhere beyond Rockall. The depression is of such great dimensions that the isobars show but little curvature, so we may take it as a fair example of parallel isobars. There is rain over Ireland and the west of Scotland, which is perhaps due to the general convergence of air in the right front of the depression. The regularity of the isobars is equally represented in the maps for 2 p.m., 6 p.m., and 9 p.m., but if we turn to the records of wind obtained from the anemograph stations we find the most remarkable fluctuations of wind force with simultaneous changes in wind direction, as well as in pressure and temperature. At Falmouth there was a sudden lull of the wind at 6.45 p.m. from a strong gale of sixty miles per hour to a breeze of twenty miles per hour, and at Plymouth, eighty minutes later, an almost instantaneous lull from fifty miles per hour to fifteen miles per hour. These changes and the accompanying changes of wind direction, pressure and temperature at Falmouth are represented in Fig. 117. From the smooth run of the isobars at 6 p.m. no one could have expected such a change. Hourly maps were therefore prepared to probe, if possible, the secret of so marked an event. All the maps presented the same smooth appearance, but the stations noting rainfall were shown grouped in a line running from Roche's Point to Sumburgh Head at 2 p.m., and from Scilly to Sumburgh Head at 6 p.m.; from Portland to Spurn Head or North Shields, with the linear arrangement much less marked, at 9 p.m. When the anemographic and other records came to be examined it appeared that the veer of wind with a fall of temperature and a shower of rain had

No 8 SUDDEN VEER OF WIND FEBRUARY 24TH, 1903



Note The dotted lines on Figs 2 3 and 4 indicate the positions of the lines along which the change of wind was taking place See Plate XVIII Fig 2
The mark ● shows that rain was falling at the hour of observation

FIG. 116.—Charts for 8 a.m., 2 p.m., 6 p.m., 9 p.m., February 24, 1903, illustrating Changes of Wind and Weather in Straight Isobars. (From "The Life History of Surface Air Currents.")



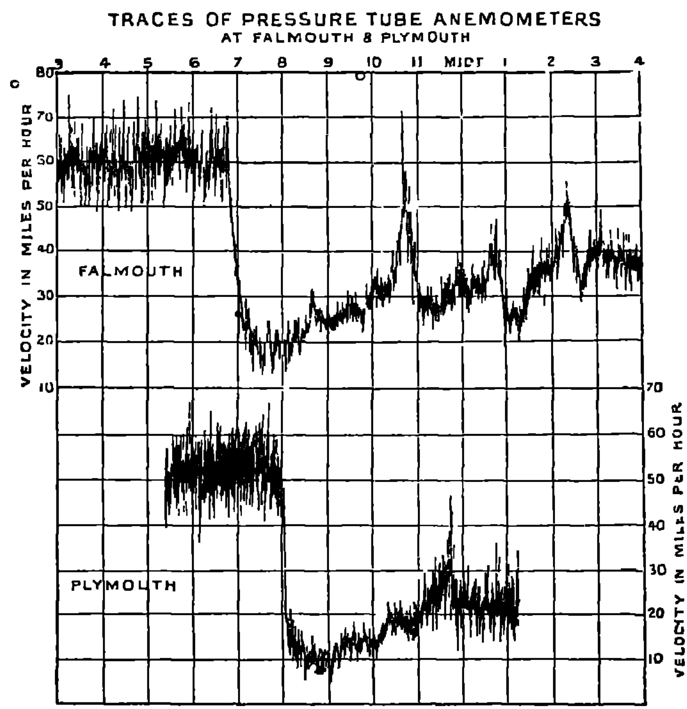


FIG. 117.—Meteorological Records illustrating the Occurrence of Heavy Rain "when the wind dropped," February 24, 1903.

swept across the country like an advancing wave—the fronts of advance in this case being represented in Fig. 119. The trajectories of air, of which the later show definite but small change of direction from the earlier ones, are given in Fig. 118.

Considering the changes of pressure shown at the various stations, we may fairly conclude that the smoothness of the

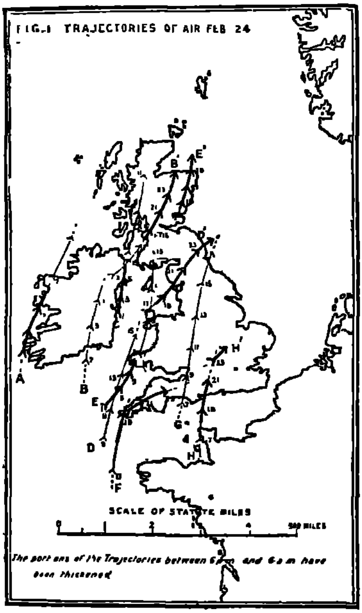


Fig. 118.

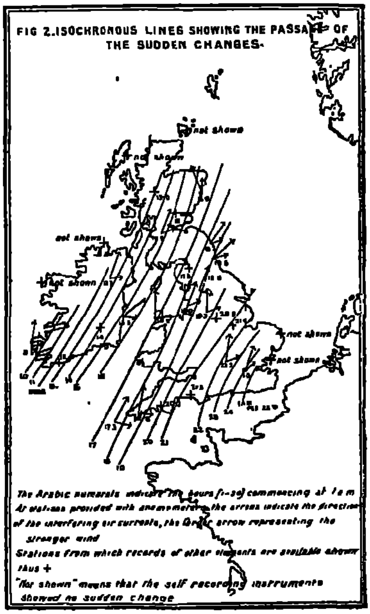


Fig. 119.

Trajectories of Air for February 24, 1903, and Isochronous Lines showing the Travel of sudden Changes of Wind across the British Isles.

isobars is due to the pardonable neglect in synchronous charts for a large area of such small details as the sudden rise of a few hundredths of an inch in pressure; and as the wind subsequently recovered temporarily its old direction, or nearly so, and something of its old velocity, the sudden transitions of the self-recording instruments were represented on the map as a gradual opening out of the isobars; but subsequent investigations of occurrences somewhat analogous have shown that

the isobars might have been drawn to show the sudden character of the changes, and that their real shape might have been somewhat similar to those shown in Fig. **120.** Such distortions could easily have been smoothed out in drawing if special attention had not been directed to the indications of the barograph.

Closer investigation indeed reveals the fact that the great westerly and south-westerly current is in itself a very complex structure and that the interactions between its component parts account foi a good deal of what is apparently capricious in its weather. (See Chap. V). Quite a number of cases occur in which a strong wind is shown veering suddenly with a lull accompanied by rain. These are certainly cases in which "it rains when the wind drops," a variant of the common saying that "it will not rain until the wind drops," for which I have long sought an explanation.

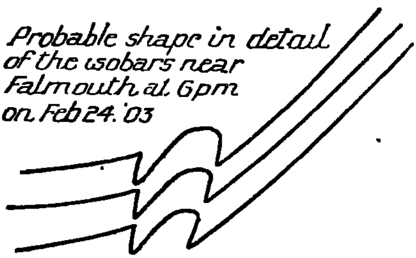


FIG 120

Here let me draw particular attention to the advancing line of rain which accompanied the changes of Fig. 117. Such rain lines are a special characteristic of westerly weather. Each station over which the line advanced would have noted a shower, and the distribution gives us the first suggestion of travelling weather in a new form and one which is quite different from the general advance of the low pressure. In this form the line of rain lies across the isobars and advances "broadside on." Its rate of travel is very well defined; in many cases it travels approximately with the velocity of the wind behind it. The line of front is easily identified on the map by the arrangement of the rain dots in a line. Thus it gives us an opportunity of forecasting not only the approach of rain but the actual time of the arrival of the

shower, if we know the velocity with which the rain-line travels.

An examination of the daily charts furnishes a considerable number of examples of such rain lines in westerly or south-westerly weather, and their introduction into forecasting promises a useful extension of our present practice. We shall examine the details of some more highly developed examples of a similar nature in the chapter on line-squalls which follows. In the meantime let me call attention to some occasions of apparently capricious distributions of rainfall in the southerly or westerly current which, although not so identified at the time, may be regarded as phenomena to be studied in relation to this part of our subject.

The first is an example of the passage of a small barometric variation over Valencia, Falmouth, and Kew in 1900, which was accompanied by a fall of a fifth of an inch of rain at each one of those stations in succession. Fig. 121A gives the autographic records from the three observatories and shows the simultaneous occurrence of a slight rise of pressure, fall of temperature, lull of wind and fall of one-fifth of an inch of rain at about 2.30 p.m. on the 22nd at Valencia, 10.30 p.m. at Falmouth, and 3 a.m. on the 23rd at Kew. Figs. 121B and 121C show the synchronous charts for 8 a.m. on the two days. The latter shows a small secondary over the North Sea which is barely indicated on the Kew barogram. The shaded area shows the region over which rain fell within the twenty-four hours.

The second is an obvious rain line shown on the 8 a.m. chart for July 3, 1907 (Fig. 122). It covers Jersey, Portland Bill, Holyhead, Donaghadee, and Malin Head, with an outlying rain point at Scilly. The rain line is related to a low pressure centre to the north-west of Ireland. At the time of its appearance on the morning map, I computed its rate of travel from the velocity of the following wind, and estimated that it would reach London at 6 p.m. Whether by accident or by the arrival of the rain line "on time," at 6 o'clock it

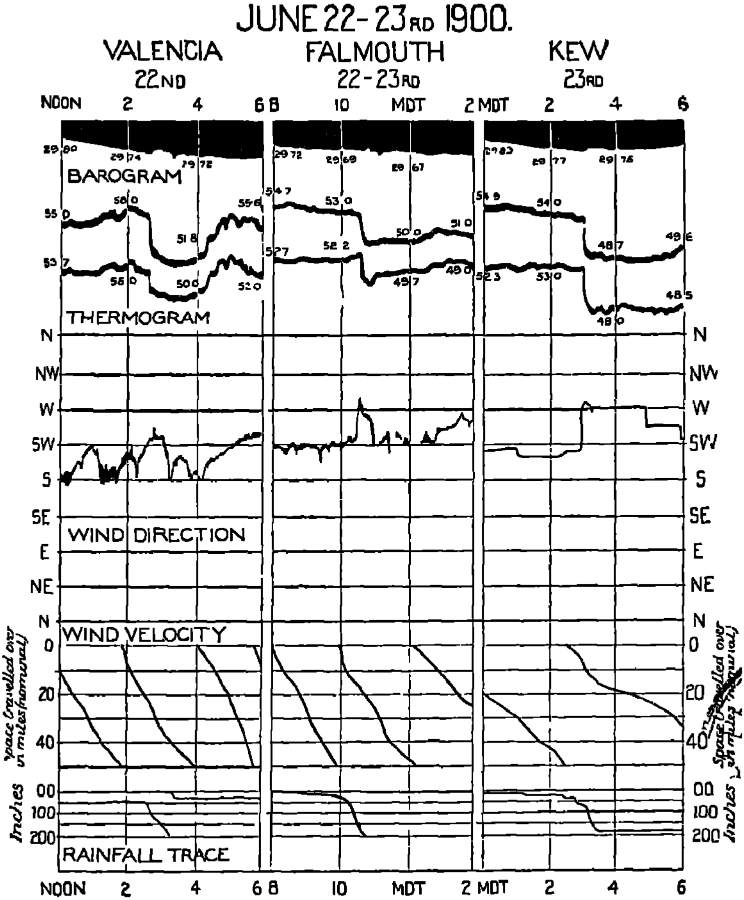
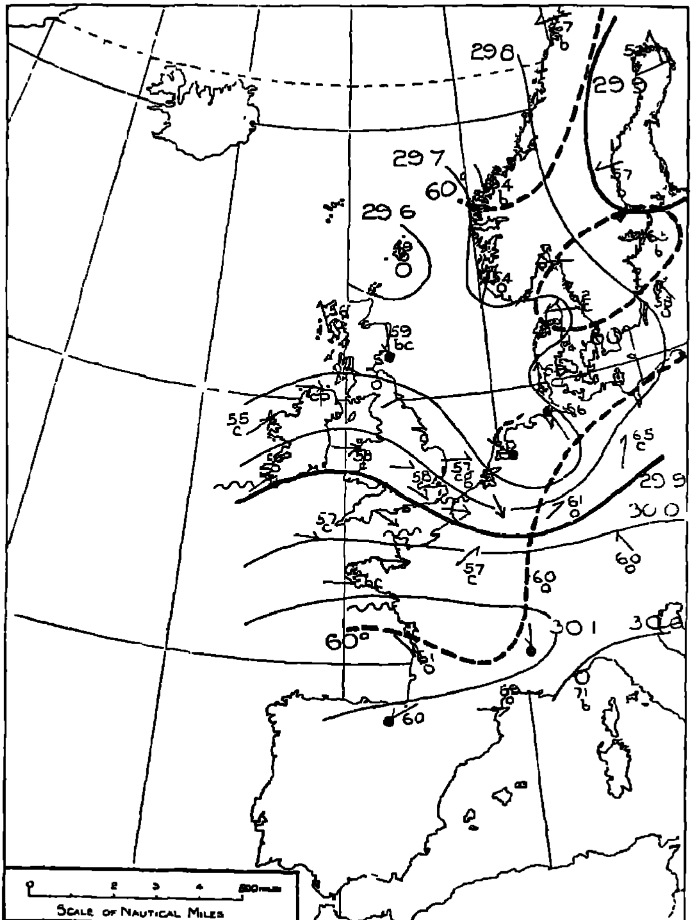


FIG. 121A.—Traces from the Self-recording Instruments at Valencia, Falmouth, and Kew, showing the Travel of Changes associated with the fall of one-fifth of an inch of Rain at each Observatory.

The data for Valencia refer to the observatory at Cahirciveen, which is on the mainland opposite Valencia Island, and those for Kew to the observatory at Richmond, Surrey, known as Kew Observatory, but not at Kew.

1900. June 22, 8 a.m.



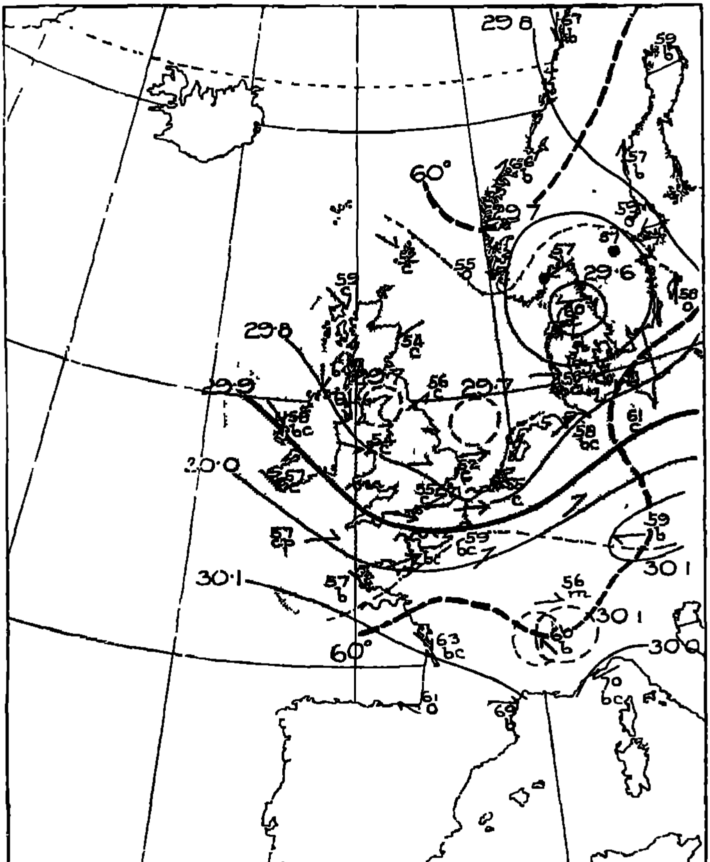
CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
29·6	1002·4	29·8	1009·1	30·0	1015·9
29·7	1005·7	29·9	1012·5	30·1	1019 3

The bold dotted lines show the isotherms of 60° F., 288·6 t.

FIG. 121B.—Showing, with the Chart for June 23, the Distribution of Pressure during the Passage of the Changes represented in the preceding Figure.

1906. June 23, 8 a m.



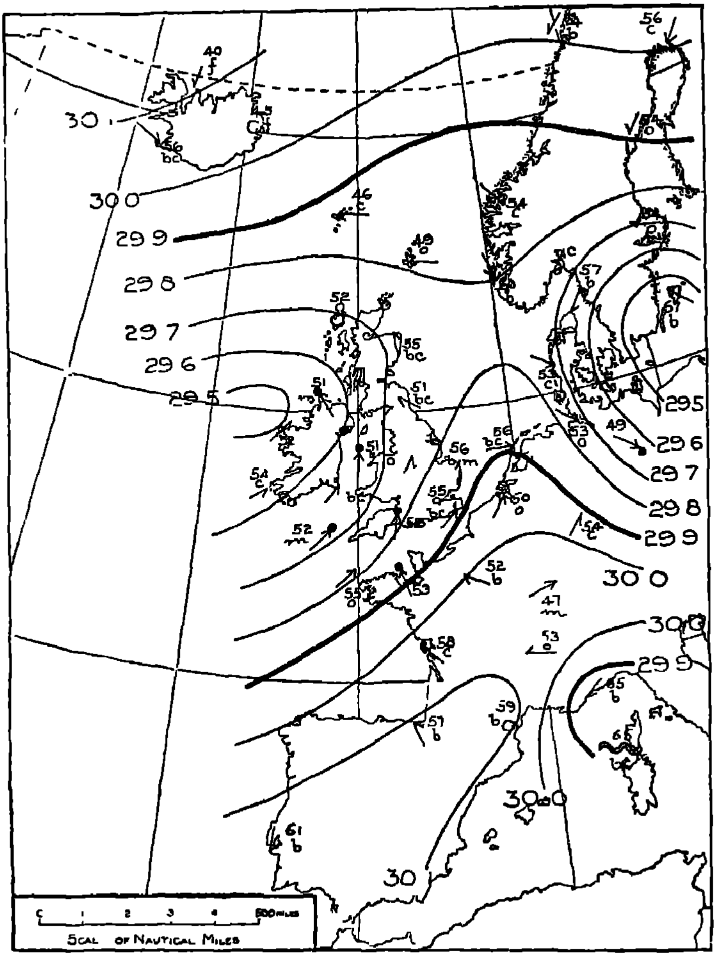
Conversion Table.

In.		Mb.	In.		Mb.	In.		Mb.
29·6	.	1002·4	29·8	.	1009·1	30·0	.	1015·9
29·7	.	1005·7	29·9	.	1012·5	30·1	.	1019·3

The area over which rain had fallen in the past 24 hours is shaded. A bold dotted line shows the isotherm of 60° F., 288·6 t.

Fig. 121c.—Chart showing Secondary Depressions probably associated with the Rainfall and other Phenomena indicated in Fig. 121a.

1907. July 3, 8 a.m.



CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
29·5	999·0	29·8	1009·1	30·0	1015·9
29·6	1002·4	29·9	1012·5	30·1	1019·3
29·7	1005·7				

FIG. 122.—Travelling Rain Line: Malin Head, Donaghadee, Holyhead, Bath, Jersey.

began to rain in London. A curious case was presented on the 25th of the same month, when a rain line, Scilly—Pembroke—Holyhead—Liverpool—Shields, made its way across England against a light easterly surface wind, but in strict obedience to the trend of the isobars round a high-pressure centre in Spain.

The explanation of some at least of these rain lines and the associated changes of the pressure and wind is probably to be found in close association with the sudden change of temperature, which is their most easily identifiable feature. This is explained by supposing that the great southerly or south-westerly current draws its air supply from different sources, and that in reality we have two currents of different temperatures running alongside. The cooler current begins to spread under the warmer one, and the spreading out of the cold air represents the advancing wave front with its shower, the change of pressure and temperature marking the boundary of its advance. Evidence is gradually accumulating for this explanation of the origin of rain lines and the line squalls to be described hereafter.

I do not wish to enter into any further discussion of the mode in which the two currents come alongside each other with considerable temperature differences between them. I have already called attention to the instructive case of February 19 to 21, 1903, when the current which brought sand from Africa found itself alongside a colder current which came from the western Atlantic with a sharp line of demarcation; and in Chapter XI. I will notice an example cited by Mr. Lempfert in his account of the line squall of February 19 and 20, 1907 (Fig. 15). In this case there was marked difference of temperature on two sides of an isobaric line along which the two currents were flowing.

These cases of the formation of rainfall by the juxtaposition of currents at different temperatures seem to pass directly into cases of the second type of rainfall formation, namely, the cutting in of a westerly current on the western side of a

southerly one. The angles between the interacting currents may vary from the parallelism of February 19 and 20, 1907, to the near approach to opposition of January 6 and 7, 1900 (Fig. 112).

CAPRICIOUS RAINFALL

It is only fair to add to the examples of the distribution of rainfall chosen to show the relation to known physical conditions some others which do not accommodate themselves to such simple explanation, and which a forecaster is justified in calling capricious.

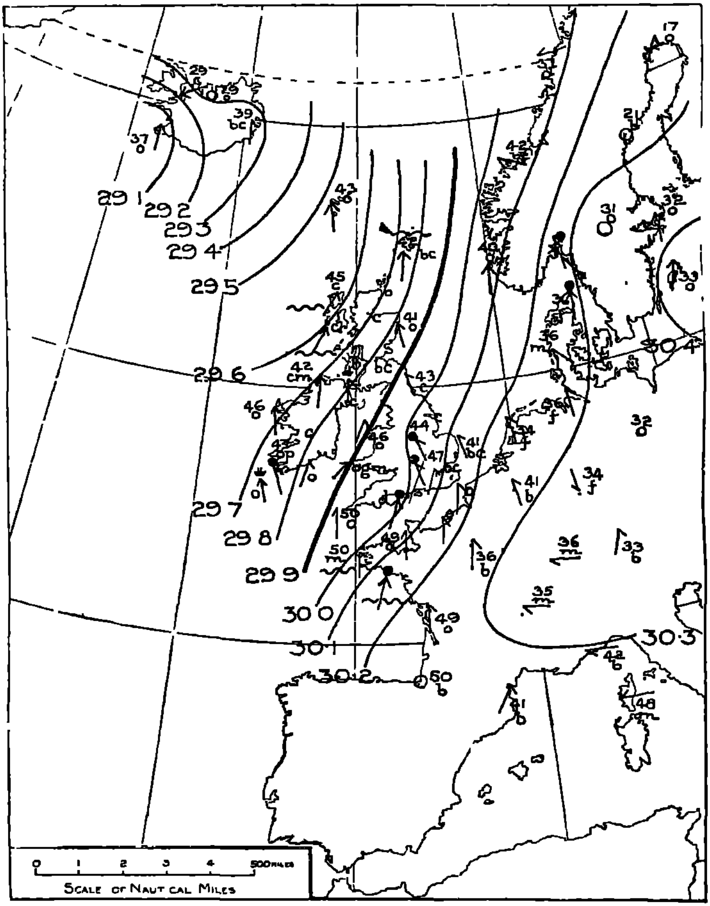
The first example is the curious one of 6 p.m. of February 12, 1904, of which the map is given in Fig. 108 on p. 277, where two regions of rainfall, apparently forming part of the front of an advancing depression, are shown to be separated by a line of fine weather identified in the chart by the succession of *b*'s between isobars crossing the east of Ireland.

The second example is one of equally capricious temper. It shows the map for 7 a.m., March 8, 1910 (Fig. 123), with a sinuosity in the isobars crossing the south of England, and rainfall associated therewith. In forecasting, this would be called a "small secondary depression," and there is no other indication, except the sinuosity of the isobar, to explain the occurrence. It seems merely casual. In drafting forecasts items of this kind are often referred to as "Rain locally" or "Some rain in places," and at present we are unable in these circumstances to say at what time or in which places.

Another example (Fig. 124) is furnished by the map for May 2, 1910, when the official forecast of the previous evening was falsified for London and the south-east of England on account of conditions which are represented by the sinuosity of the 30·1 isobar. The isobar in question formed part of a large anticyclonic system that seemed to promise fine weather over the whole country. But see p. 301.

The fourth example, that for April 16, 1910 (Fig. 125), is adduced because it shows conditions under which rainfall is

1910. March 8, 7 a.m.



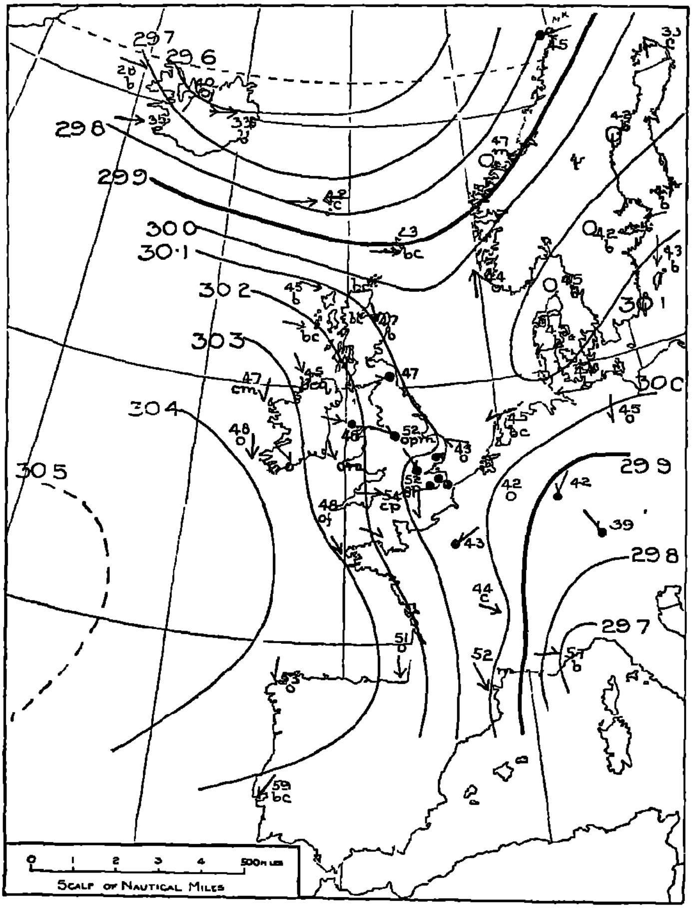
CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
29·1	985·4	29·6	1002·4	30·1	1019·3
29·2	988·8	29·7	1005·7	30·2	1022·7
29·3	992·2	29·8	1009·1	30·3	1026·1
29·4	995·6	29·9	1012·5	30·4	1029·4
29·5	999·0	30·0	1015·9		

FIG. 123.—Chart showing Capricious Rainfall in "Straight Isobars" of the Southerly Type.

NOTE.—It is important to remark that the sinuosity in the isobar such as that shown in this chart may be analysed into a small rotating system superposed upon the straight isobars.

1910. May 2, 7 a.m.

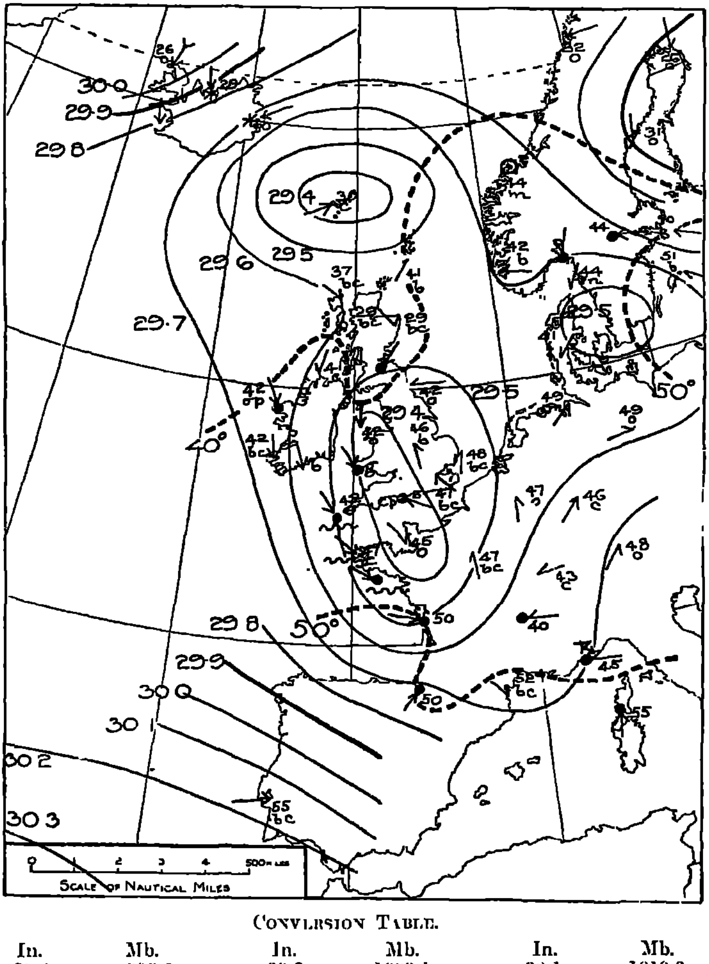


Conversion Table.

In.	Mb.	In.	Mb.	In.	Mb.
28·6	968·5	29·3	992 2	30·0	1015·9
28·7	971·9	29·4	995·6	30·1	1019·3
28·8	975·3	29·5	999·0	30·2	1022·7
28·9	978·6	29·6	1002·4	30·3	1026·1
29·0	982·0	29·7	1005·7	30·4	1029·4
29·1	985·4	29·8	1009·1	30·5	1032·8
29·2	988·8	29·9	1012·5		

Fig. 124.—Forecast Failure and Exceptional Case of Rainfall. A thoroughly wet and gloomy day in London in front of an ordinary Anticyclone.

1910. April 16, 7 a.m.



CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
29·4	995·6	29·8	1009·1	30·1	1019·3
29·5	999·0	29·9	1012·5	30·2	1022·7
29·6	1002·4	30·0	1015·9	30·3	1026·1
29·7	1005·7				

A bold dotted line shows the isotherm for 40° F., 277·4 t.

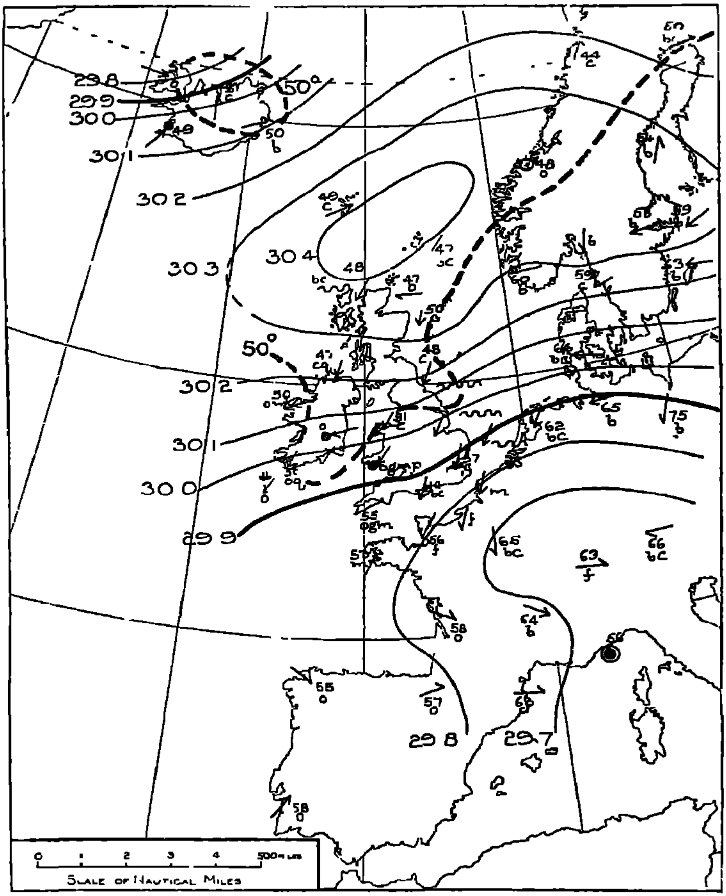
FIG. 125.—A Day of Thunderstorm, with Floods, near London. Rain in the North and West of a Cyclonic Depression.

always capricious, and also because it shows rain in that part of a cyclonic depression where the east wind changes into a north wind. It is difficult in that case to form an opinion as to where the water comes from. The fact that very heavy local rainfall, causing floods, was experienced in the north of London, following on thunderstorms in the north-west of England of the day before, probably shows that the vertical structure of the atmosphere was on this occasion very complicated. The intrusion of an area of cold from the north, as shown by the isotherm of 40° on the chart, is very noteworthy in connection with the local rain in the north and west.

RAIN IN THE UPPER AIR

The suggestion of a complex vertical structure producing rainfall, which is unexpected either in locality or amount, leads on to the example of June 6, 1910 (Fig. 126), and the remarks upon rainfall in the upper air which conclude this chapter. The map for 7 a.m., June 6, shows rain in South Wales and central Ireland in a north-easterly current of air which had previously had ample opportunity of depositing any moisture which it might have brought from the high-pressure region over the northern Atlantic. Rain in such conditions is beyond the forecaster's horizon. There is indeed a slight sinuosity of the isobar, and doubtless it is connected as usual with the formation of rain. But then there is nothing upon which to form an idea of the locality, duration, or extent of the rainfall. On this occasion I was curious to find out whether there were any facts available to explain the apparent caprice. Mr. Cave, of Ditcham Park, Petersfield, was good enough to give me his weather notes, from which I quote the following:—"June 6, 2 a.m. to 3 a.m., thunder and lightning, most flashes from cloud to cloud; 8 a.m., very heavy rain, with l. and t. Rain stopped about 9 a.m. Surface wind northerly, with scud, cumulus from east-south-east persisting till 9 a.m.," in continuation of similar conditions of cloud motion observed the day before. It is clear that in this

1916. June 6, 7 a.m.



CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
29·7	1005·7	30·0	1015·9	30·3	1026·1
29·8	1009·1	30·1	1019·3	30·4	1029·4
29·9	1012·5	30·2	1022·7		

The bold dotted lines show the isotherms for 50° F., 283 t.

FIG. 126.—Heavy Rainfall with North-Easterly or Northerly Winds unaccounted for by Surface Conditions.

case the northerly surface wind was a thin layer. The source of the water for the thunderstorms should possibly be looked for in the south-easterly current aloft. The surface wind might have produced some influence by fluctuations in its depth, but it would be simply a cushion over which the rainy air travelled.

In this chapter I have endeavoured to supply an explanation upon physical grounds of the formation of rainfall associated with travelling depressions. In doing so I have shown how the causes of production of rainfall may be supposed to operate to produce rain in the right and left fronts of an advancing depression, along the trough line and also along other lines in the region of the westerly or south-westerly currents. I have made use of the evidence to be obtained from observations upon surface currents. I *do not* overlook the fact that the formation of rain is *not* in itself a surface phenomenon. In that connection the surface may be only the recipient of a by-product of operations conducted entirely aloft. The changes of pressure which take place in the upper air must always be transmitted to the surface, so that we can always be in possession of that amount of information, but the magnitude and direction of the air currents and the changes of temperature are not necessarily known to us.

The table on p. 220 shows that the weight ratio of water vapour to dry air in saturated air is reduced to one-tenth of the surface ratio at about 17,500 feet above sea level, where only one thousandth part of the pressure can be due to water vapour. Operations on a very vast scale would be necessary to produce any appreciable rainfall with so little water material, consequently we may suppose that rainfall in any effective sense is limited to the lowest 17,000 feet. Much may take place within those limits unobserved at the surface, and consequently it behoves those who endeavour to account for rainfall to remember the unexplained possibilities of the upper air. We are, however, not without hope of getting effective

information on the subject. Observations of clouds have been made for a long time, and in later times observations of pilot balloons promise fruitful results for the stratum about which students of the formation of rainfall want to know most.

It is much to be wished that we could disentangle the pressure records of the surface and sort out the parts due to the different portions of the atmosphere, but at present we are hardly able to claim much knowledge on that subject in a form which can be applied to a single synoptic chart.

Two other forms of rainfall have also to be noticed, namely the orographic rainfall due to the mechanical obstruction of elevated land to the passage of a current of air and the rains which occur during thunderstorms, due to some instability of the atmosphere hardly shown on isobaric charts.

Much might be added about the relations of cirrus cloud and other phenomena usually held to be indicative of an approaching depression as distinguished from the individuality of its component currents. In many of the suggested associations the vast dimensions of a cyclonic depression have hardly been realised. The extent of the visible sky is at most 300 miles, and that distance is often only a part of the width of a cyclonic depression. Probably many of the phenomena which are regarded as indicative of an approaching cyclone belong to the great air current on the southern side.

CHAPTER X

THE STRUCTURE OF TRAVELLING CYCLONES

RECENT investigations of the details of the phenomena of travelling cyclonic depressions in continuation of a line of thought similar to that of Chapter IX. have led to generalisations about the structure of cyclones which are already recognised as important in forecasting. Of these investigations the best known are those of the Geophysical Institute of Bergen under the direction of Professor V. Bjerknes, in association with which the names of J. Bjerknes, H. Solberg, T. Bergeron are especially prominent. The developments referred to arose from the close investigation of the conditions for rainfall in the south of Norway during the war, when the supply of information from other countries necessary to form an ordinary weather-chart for the purposes of daily forecasts was extremely restricted and yet the economic pressure resulting from the war made the necessity for trustworthy information as to the probable course of the weather more urgent. The plan which was followed was to obtain telegraphic information about wind and rainfall from some hundreds of stations in the south of Norway and to study the instantaneous *lines of flow* of air over the surface in relation to the rainfall associated therewith. The idea of lines of flow may be understood from Fig. 94 (p. 257), where the instantaneous lines of flow between regions of high pressure and low pressure over the Atlantic are shown by the red lines which take the form of double spiral curves. We have seen in Chapter IX. that these lines do not represent the actual paths of the air from day to day, but they show the "field of flow" at any particular moment. The idea of using them in order to form an opinion of the general kinematic structure of the atmosphere and to indicate points of convergence and divergence for the time being had already been developed by Professor

V. Bjerknes and others in two volumes on "Dynamic Meteorology and Hydrography," published by the Carnegie Institution of Washington. The first volume (Part I., Statics) is dated 1910, and the second volume (Part II., Kinematics, with a supplementary volume of plates), 1911. The areas to which the method was then applied were large, such as Europe and the United States, and the scale of the charts was so small in relation to the details of rainfall that only general conclusions as to the meteorological consequences of the flow were traceable. The application of the same method in much greater detail to the more restricted area of southern Norway yielded definite relations between the flow of air over the surface and the localities of rainfall, particularly of summer thunderstorms. The primary results of the investigation are set out in a lecture by Professor Bjerknes before the Royal Meteorological Society [1] in 1919. An example of the use of the lines of flow for this purpose is given in Fig. 127.

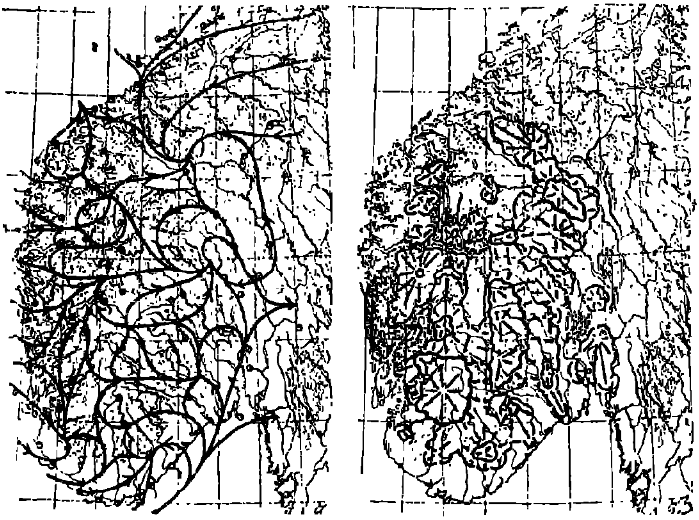
THE REFERENCE TO THE LINES OF WARM FRONT AND COLD FRONT

To these conclusions as to local rainfall J. Bjerknes added the discovery of two lines of discontinuity in wind and temperature which, starting from the outside, cross the isobars of a travelling cyclone and meet at the centre, and further, these lines of discontinuity were found to be closely associated with the distribution of rainfall within the area of the cyclone. The discontinuities were explained as delineating the ground plan of a complicated sheet of discontinuity which separates cold polar air from warm equatorial air as already described in Chapter V., and has become well known in meteorological literature as the Polar Front.

The figure which J. Bjerknes put forward as representing the division of the cyclone in this way is given as Fig. 60. It is noted by Professor V. Bjerknes as being a development of Fig. 111, which presents a diagram representing the constituent parts of a cyclonic depression as indicated by the life-history of surface air

[1] "Q. J. Roy. Met. Soc.," vol. 46, p. 119, 1920.

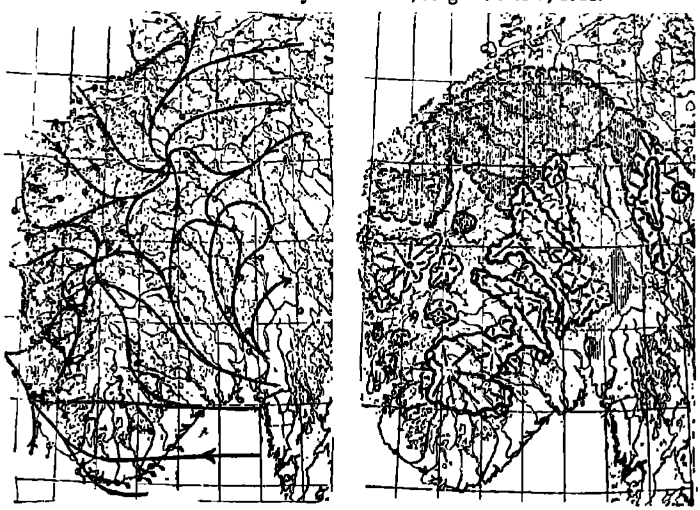
FIG. 127A.—Fifth Day of Showers, August 2 to 3, 1918.



a. Air-Motion—Lines of flow at 2 p.m., August 2.

b. Areas swept over by Showers (outlined). Areas of Soft Rain in the Night (shaded).

FIG. 127B.—Sixth Day of Showers, August. 3 to 4, 1918.



a. Air-Motion—Lines of flow at 2 p.m., August 3.

b. Areas of Showers (outlined). Areas of Continuous Rain (shaded).

FIG. 127.—Lines of Flow of Air leading up to the Formation of Local Showers and Rain in Norway. ("Q. J. Roy. Met. Soc.," vol. 36, 1920, p. 137.)

currents. An examination of the run of the isothermal lines and of the winds on the maps of the previous chapter shows that this discovery of the division of well-developed cyclones into two parts separated by lines of more or less marked discontinuity of wind, temperature and rainfall, gives an effective generalisation of the salient features. We may refer particularly to Fig. 38, the course of the isotherm for 15° with the small secondary developed on the squall-line; Fig. 12, the isotherm for 40°, and the rainfall associated therewith; Fig. 51, the course of the isotherm of 40° again and the rainfall: Fig. 105, the rainfall associated with the steering-line (warm front) and the squall-line (cold front); Fig. 107, the isotherm for 40° and the rainfall; and Fig. 110, the isotherm for 42°. These numerous examples show clearly enough that the new analysis marks a definite advance in our knowledge of cyclonic depressions and enables us to refer the properties of a cyclone at the surface to the two lines, the warm front or steering-line drawn from the centre to form in its initial stage a tangent to the path of the cyclone, and the cold front or squall-line proceeding from the centre along the trough of the depression, instead of relating all the phenomena of the cyclone somewhat vaguely to the centre. The association of the rainfall with the two fronts is particularly expressive and effective for the purpose of forecasting.

THE DEATH AND SUCCESSION OF CYCLONES

And since its discovery the doctrine of the polar front has been pushed much further. It has been found that the rate of advance of the cold front may be so rapid that its demarcation on the ground may reach that of the warm front, and thus a portion of equatorial air may be completely surrounded at the ground by the colder air of the polar front. When that happens the supply of warm air to the central region of the cyclone is cut off and the cyclone consequently fills up and expires. At the point of overlapping of the two fronts a new cyclonic centre tends to form first as a secondary and finally as having absorbed the energy of its own primary. Hence we find a succession of cyclones generally in groups of four, successively further south. They are followed

by a new primary cyclonic centre in the far north which goes through the same process. A fresh family of cyclones begins.

The family of the cyclones takes on the average about six days to cross a meridian and thus it gives us a six-day period of cyclonic weather with subsidiary cyclones between.

THE ORIGIN OF ATMOSPHERIC VORTICES

These conclusions in so far as they are an accurate representation of the medley of facts which constitute our weather, must obviously be of great importance in forecasting the details of a sequence of weather, and the results already formulated have proved to be of material assistance for that purpose.

So far they are empirical generalisations of the facts, just as were the conclusions set out by Abercromby and others, for the association of weather with the passage of cyclones and for the direction and rate of their progress. They are obviously in accord with the descriptions of the phenomena exhibited at the surface during the passage of cyclonic depressions as described in Chapter IX., particularly on p. 275, the association of rain with the two lines of discontinuity and their relative positions are natural developments of the views therein expressed. The question that arises is whether those discontinuities should be regarded as more or less peculiar to the lowest layers of the atmosphere where we know there can be no balance between pressure and motion and where areas of low pressure must be continually invaded by air from outside or as extended upwards to the limit of the atmosphere, as defined by the existence of clouds. The former view would be a natural consequence of the flow of cold air from the high levels of Greenland or the cold Asiatic anticyclone in winter, whereas the latter would depend on the general properties of the atmosphere and the tendency for distribution to take place according to temperature and air-motion. Professor Bjerknes is inclined to the second of the two alternatives which have been referred to. He has treated the discontinuity between cold and warm air as a natural consequence of the dynamical conditions of the atmosphere on a rotating globe and concludes that it extends from the surface upward throughout

the region in which the phenomena of cloud and rainfall are experienced; that the phenomena of the cyclonic depressions of middle latitudes begin with convolutions of the surface of discontinuity due to the instability of adjacent warm and cold air in relative motion, and that the travel of the associated phenomena can be represented as the consequence of wave-motion along the front which is a natural dynamical result of a surface of discontinuity in a fluid-medium with difference of flow on the two sides. At sea-level they appear as collections of approximately circular isobars because the surface of discontinuity is not vertical but tends towards parallelism with the polar axis or even less inclined to the surface than this line.

The general dynamical theory may also be applied to account for the more general phenomena of the thermal structure of the atmosphere and the general circulation.[1]

If these conclusions are well founded the idea of vortices or whirls of revolving air with axes more or less vertical, which has held the field for some sixty years, must be greatly modified, and perhaps regarded as applicable only to the final stage of the life-history of the cyclone when its supply of equatorial air has been cut off by the overlap of the cold front over the warm front. From the time of the early telegraphic synoptic charts, the cyclones of middle latitudes were regarded as of the same nature as the tropical revolving storms which had from the first been regarded as examples of vortices of revolving air. We are now invited to modify that view and to look to the development of the theory of wave-motion at the mutual boundary of two discontinuous fluid-media to supply its place.

THE EVICTION OF AIR

In face of the discontinuities which are apparent at the surface and to which attention has been called in the examples quoted in Chapter IX. that conclusion need not cause much surprise. It obviously challenges the question of the evidence for the

[1] See V. Bjerknes, "On the Dynamics of the Circular Vortex with Applications to the Atmosphere and Atmospheric Vortex and Wave Motions" ("Geofysiske Publikationer," vol. 2, No. 4, Kristiania, 1921).

existence of columns of air travelling as separate dynamical entities. It is curious that while the Norwegian meteorologists have been developing ideas about cyclones which tend to show that the evidence for the existence of any such entities is untrustworthy, there has been accumulating, on the other hand, a certain amount of evidence which tends in the other direction. In 1917 the late Lord Rayleigh [1] reviewed the theory of revolving fluid in the atmosphere and showed that, provided that there were already some vorticity in the atmosphere, all that was necessary in order to develop a vortex in the sense in which it has been generally understood was the removal of air from the region which would form the core of the resulting vortex, and more recently D. Brunt [2] has shown that the rotation of the earth itself causes sufficient vorticity for the purpose. The primary difficulty was that weather maps showed little actual sign of the distribution of pressure, temperature and wind which the existence of such vortices would imply.

CYCLONIC CENTRES IN THE GENERAL ATMOSPHERIC VORTEX

But there are two reasons for that omission which are obvious enough when they are stated, but which were certainly not at the time in the minds of students of weather maps. The first reason is that a vortex formed in the manner postulated by Lord Rayleigh cannot be regarded as being developed in a quiescent atmosphere; it will be formed in some air-current which may be the current of some great cyclonic circulation or in the general circulation of the atmosphere itself, which, northward of the tropical anticyclones of the northern hemisphere, forms a great circumpolar whirl and southward of the great anticyclones appears as a belt of air, not far short, at any rate, of one-half of the atmosphere moving from the east round the equator. Below latitude 50° the westerly circumpolar circulation is found more or less intermittently at the surface; further north it may not appear at the surface, but is found at levels above two or three kilometres. If a vortex is formed in one or other of these great planetary or cyclonic currents

[1] "Proc. Roy. Soc. A.," vol. 93, p. 148, 1917.
[2] "Proc. Roy. Soc. A.," vol. 99, p. 397, 1921.

it must be carried along with the current and its progression may be regarded as conditioned by the current in which it is formed. We thus get a conception of a main current which determines the travel of vortices in place of the composite wave-motion which the new theory suggests. When we look for the evidence of such vortices at the surface we must remember that the distribution of pressure and wind must be that of the combination of the vortex and the current which carries it. The result of the combination is not a series of circular isobars with uniform distribution of winds, but a curious assemblage of curves that has two points of no gradient of pressure and two points of no wind. One of each pair of points is near the centre, not quite coincident, and the other pair is on the north side of a vortex in a westerly current, and again the two points are not coincident. Hence, a somewhat complicated figure of pressure and winds results, which can, however, be analysed into two separate systems of rotation and translation.

The analysis of actual maps in this sense is not generally easy because we have no satisfactory estimate of the current in which the vortex may be existing. But we have some evidence in favour of the view. For example, the travel of tropical revolving storms is at the rate of about 10 miles per hour, not much different from the normal wind of the localities where they are formed. They circumnavigate the tropical regions of high pressure much in the same way as we suppose an air current would. For our own latitudes Mr. Silvester has taken out from the charts of the Monthly Weather Report the average rates of travel of those cyclonic depressions which followed the more regular or more frequent paths, that is to say, the tracks of depressions which moved westward were disregarded. The results are as follows :—

Rates of Travel of Cyclones in Miles per Hour.

	Range.	Mean.		Range.	Mean.
January . .	0—80	25	December . .	5—69	26
February . .	5—63	23	November . .	3—77	23
March . .	5—65	22	October . .	4—62	24
April . .	4—82	23	September .	5—50	21
May . .	4—57	18	August . .	3—72	20
June . .	3—60	20	July . .	4—54	21

Mr. Silvester remarks that these rates of travel are much faster than the mean velocity of the air-drift computed from the mean isobars of the surface, which is 15 miles per hour in December and only 2 miles per hour in May ; the difference would be greatly modified if the omitted tracks were brought into account.

The case is somewhat different for the upper air. The velocity of the air current which corresponds with the normal distribution of pressure at 4,000 metres according to the charts of Teisserenc de Bort is 20 miles per hour for January and 14 miles per hour for July, and these values take account of such abnormalities as are related to the tracks omitted by Mr. Silvester. A reduction of 20 per cent. from the observed velocities on that account would bring the values down to 20 and 16 miles per hour.

Moreover, sometimes one can identify the phenomena as those of a circular vortex travelling in the main current of a great cyclonic circulation ; the example of the small secondary of March 21, 1895 (Fig. 38), is a case in point, also that of the tornado of October 27, 1913, described in " Geophysical Memoir," No. 11, (M.O. 220a) (Fig. 179). The map for January 8, 1922, shows another example when the peculiar figure suggested in the preceding paragraphs is realised and the possibility of analysis is therefore obvious. See "Manual of Meteorology," Part IV. Cambridge University Press, 1919.

THE FLOW OF AIR TO THE INTERIOR OF CYCLONES

The second reason why vortices cannot easily be recognised on a map is that a vortex requires for the protection of the low pressure of its interior a certain velocity of circulation in the air which surrounds its core. It is impossible to maintain that velocity in the upper air and at the ground at the same time because the friction of the air moving over the ground transforms part of the energy of its motion into irregular eddies and the effective or equivalent velocity is therefore reduced at the ground. Hence, either the air is moving too fast up above or too slow at the ground for the balance which is necessary to preserve the core. If the first of the two alternatives happened, the vortex would expand

and its velocity would be reduced, so it is the second alternative which we have to face sooner or later; the velocity at the bottom is not enough to keep the air out, and consequently the core is invaded by the inward flow of air at the bottom. The bottom layer is of a very composite character and consists of air with much eddying motion. Consequently the flow along the bottom, which is in fact very similar to and easily mistaken for the flow which is set up when the core is first removed and the vortex formed, introduces some very heterogeneous material into the interior of the organism and has important secondary effects. It may cause the vortex gradually to fill up, and, on the other hand, it may set up local convection which adds to the vortical energy and may thus be the means of saving the cyclone from decay. It is at or near the ground that any such effects will first be felt, and consequently the ground layer of what is a regular vortex up above is liable to show very irregular structure.

SYMMETRY IN THE UPPER AIR

Hence the want of symmetry which we find at the surface may be only a source of strength and permanence. For the regions up above we have some evidence of symmetry which certainly does not exist in the surface-layers. Mr. W. H. Dines has found very high coefficients of correlation ·8 to ·9 for the relation between changes of temperature and changes of pressure taken haphazard at levels between 3 and 8 kilometres, whereas there is no correlation at the surface and the correlation is negative above 10 kilometres. The conclusion from these facts *primâ facie* is that temperature is symmetrically distributed with respect to centres of low pressure in the region between 3 and 8 kilometres where we may expect the air-currents of the general circulation to be freed from the irregular disturbances of lower levels.

THE ENERGY OF VORTICES

Dr. Fujiwhara has shown[1] that when a vortex has become symmetrical it necessarily decays and that some differentiation

[1] "Q. J. Roy Met. Soc.," vol. 47, p. 287, 1921.

from symmetry is necessary for its continued existence. He has further shown that vortical motion is a general law of the whole atmosphere. It contains imperfect vortices of all sizes from the infinitesimal scale which causes ordinary viscosity, to the gigantic scale of the circumpolar circulation ; we may even go beyond that to the vortical arrangement of the solar system and of the spiral nebulæ. Local irregularities mean local vortical energy which in favourable circumstances can be taken into the energy of existing vortices of the next larger degree. So any local disturbance resulting in a want of symmetry in a cyclone may help to feed the energy of the vortex. On the other hand, a great vortex may dissipate itself by developing a series of secondaries or vortices of the next lower degree.

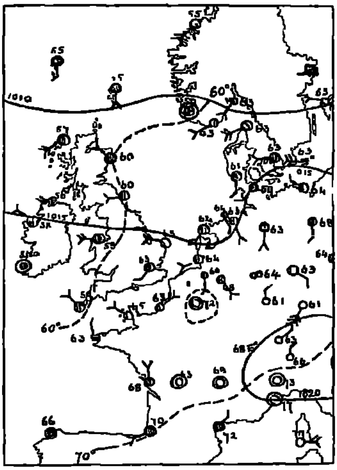
The initial step in the process of the addition of energy may be the removal of part of the central portion, which produces rainfall. In that way Lord Rayleigh's requirements for the development of cyclonic motion would be satisfied. We can understand that local convection may occur under various circumstances of instability, and whenever it does occur rainfall is generally the direct consequence; the removal of air by the eddy-friction between the rising air and its environment, which elsewhere we have called eviction.[1] is a secondary effect which results in an increase of the energy of the cyclone.

It will easily be understood that this is not the only form of convection or elevation of air which produces rainfall. The fact that the central regions of a cyclone are ineffectually guarded at the bottom on account of the lack of velocity implies that air is always accumulating at the bottom and lifting the upper layer. The effect of such an accumulation cannot be very different from what is represented as the sliding upward of the warm front over the polar air in Fig. 60.

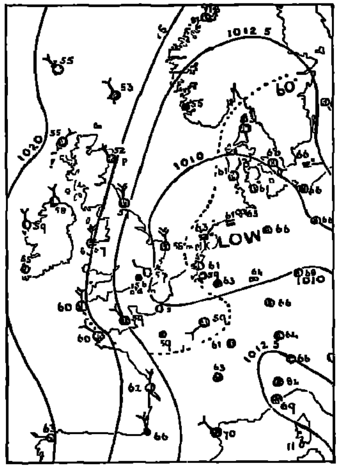
The question remains as to what is the process of removal of air which Lord Rayleigh's theory assumes. We have suggested the penetrative convection of rising air as the origin of the process. not the automatic rising of a coherent mass, but the scouring action

[1] "The Air and its Ways." Cambridge University Press, 1923

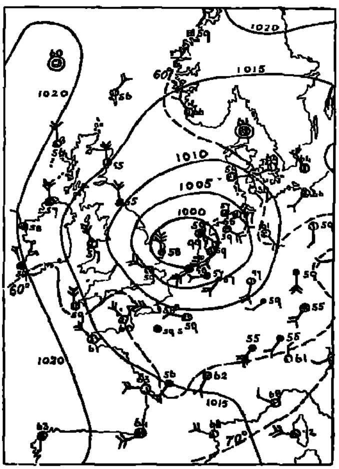
1917. July 27 to August 6.



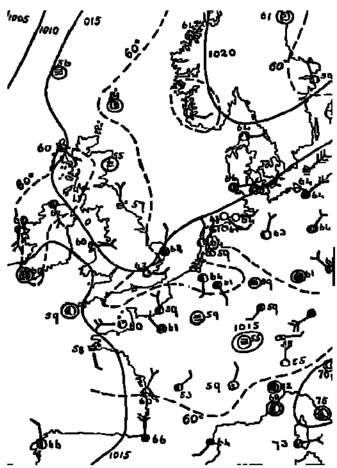
1917. July 28, 7 h.



1917. July 30, 7 h.



1917. August 3, 7 h.



1917. August 6. 7 h.

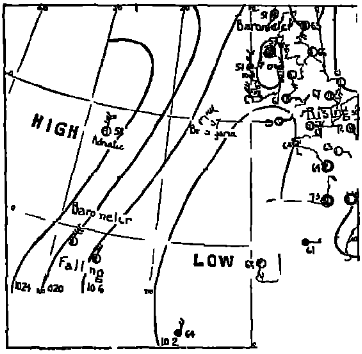
FIG. 128.—Depression which developed and filled up without moving.

of whatever penetrative convection may happen to take place. For the mode of operation we have suggested eviction ; but the disposal of the air which reaches the top of the vortex has still to be accounted for. We have, at the same time, to seek a cause for the development of local areas of high pressure and the maintenance of the great permanent anticyclones of the globe. That may be a possible destination of the air which has been removed. but it is only fair to say that we have as yet no direct evidence for it. On the other hand, we have some direct evidence of the formation of cyclones *in situ* and their filling up without any travel and by no other apparent process than the removal of air following the convection of local rainfall and the filling up of the vortex by the creeping inwards of air at the bottom.

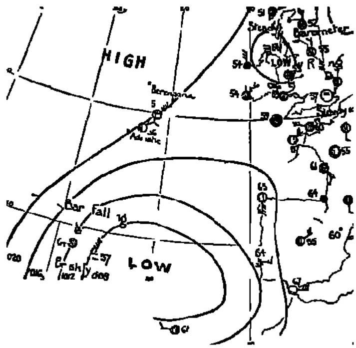
We give two instances, the first the cyclone of August 3, 1917, in the North Sea (Fig. 128). The amount of air removed in that case is 70.000 million tons ; and the second is that of October 10 to 15, 1921 (Fig. 129), in the Atlantic between the Azores and Madeira, when the amount of air removed was 190.000 million tons.

There is thus still something to be said for the idea of a vortex carried in the current of a larger circulation as representing the kinematical conditions of tropical revolving storms and of some at least of the cyclonic depressions of middle latitudes. There is still opportunity for further investigations both on these lines and on the lines of the theory of the polar front. As with all novel and striking theories, with the latter fresh in our minds we are naturally disposed to find illustrations of it without considering whether they are compatible with an alternative explanation. Any discontinuity is at once assumed to be an effective example and to be the local representation of the one great discontinuity. The actual situation appears to be that by making more or less plausible assumptions the general character of the phenomena of cyclones can be represented mathematically as originating in wave-motions in two media of different density separated by a discontinuity, and the pole is a suggestive source of such discontinuity. It is, however, not the only one. The northern slopes

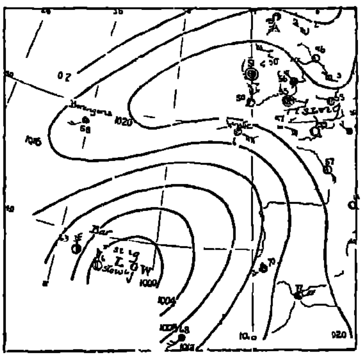
1921 October 10 to 15.



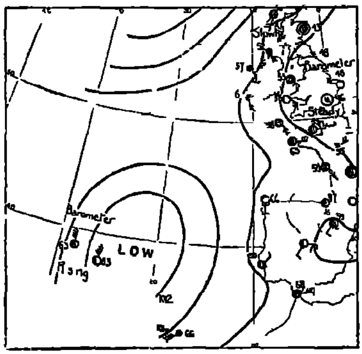
1921. October 10, 18 h.



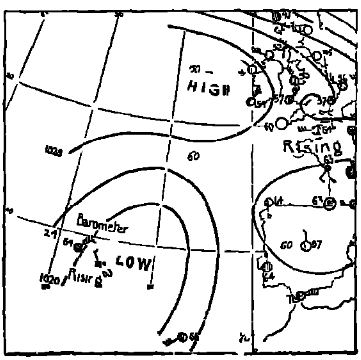
1921 October 11, 7 h.



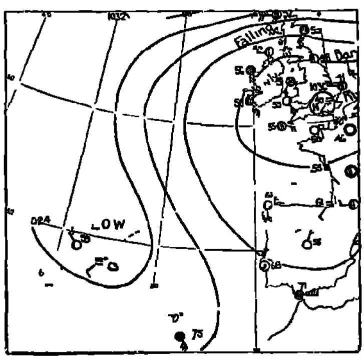
1921. October 12, 7 h



1921 October 13, 7 h.



1921. October 14, 7 h.



1921 October 15, 7 h.

FIG 129.—Depression over the Atlantic which developed and filled up without travelling.

of the Asiatic Continent are an effective substitute for the pole, both in winter and in summer. The mere unexpectedness of the theory tends to make it obscure the more obvious lines of explanation of the phenomena as a complication of vortices; and, moreover, since wave-motion in a travelling medium is circular motion combined with translation, and vortical motion in an air-current can be generally described in the same words, it is not altogether clear that the distinction is so fundamental as it would appear to be to those who are unfamiliar with complex dynamical systems.

THE DISCONTINUITIES AND UBIQUITY OF VORTICAL SYSTEMS

It is apparent that if the idea of the atmosphere being full of imperfect and unsymmetrical vortices of all sizes—all tending, as Dr. Fujiwhara would say, towards symmetry with respect to a vertical axis—is to be regarded as correct, we ought to be able ultimately to analyse our weather maps into a combination of vortices. The task is certainly beyond our power at present, because at the outset we do not know what to take for the original current in which the temporary vortices are formed; but the inquiry need not be entirely unproductive. The maps of the following dates seem to invite an attempt at analysis: 1920, July 17, 23; August 19—25; September 21; December 2; 1921, January 5, 7, 8, 9. January 8 has already been adduced in illustration. Such an analysis is an attractive problem for the student of weather maps. And in any case many meteorologists of experience will feel impelled to seek some avenue of escape from the diagram which Professor Bjerknes puts forward as representing the general circulation of the atmosphere. It contains two features, which to many of us seem impossible, even on a globe without continents or coastlines; one is a general and uniform flow of air all round the globe from the tropics to the equator, which would result in velocities far exceeding anything that is known to exist, and the other is the representation of descending and ascending currents comparable with the flow of the trade-winds which would give quantities of rainfall unheard of

in any part of the globe, and anticyclonic regions consisting of air in a condition of labile equilibrium which those meteors never possess.

However that may be, the analysis which Professor Bjerknes has given in the paper referred to of the formation of waves by relative motion at a surface of discontinuity and the degeneration of waves into vortices is a most valuable contribution to the study of the properties of the atmosphere. In making his applications he has had regard to certain special examples of discontinuity, namely those between equatorial and polar air. But if we regard the stability of the atmosphere as conditioned by the run of the surfaces of equal potential temperature we must accept the conclusion that the atmosphere is full of approximations to discontinuity, and processes, similar to those which give rise to waves and vortices in the polar front, are more or less ubiquitous and fill the air with waves and vortices, as Dr. Fujiwhara suggests.

CHAPTER XI

THE MINOR FLUCTUATIONS OF PRESSURE—LINE SQUALLS AND LIGNES DE GRAIN

The reader's attention will next be asked for the consideration of the further development of the investigation which began with the life history of surface air currents and the relation of barometric gradient to wind force. The investigation has been continued in the Meteorological Office as opportunity offered. The results have been given partly in lectures or in papers before scientific societies, which include a paper on "The Line Squall of February 8, 1906," by Mr. R. G. K. Lempfert,[1] who was my personal assistant at the Office when the work began, and one on "Line Squalls and Associated Phenomena," by Mr. Lempfert with Mr. R. Corless, who occupied that position from 1907 until 1915.

We saw in Chapter IX. that some of the most striking phenomena of westerly weather are directly related to changes of pressure shown on the barogram as slight deviations from the regular march of the trace. We have attributed the changes to a flood of a different kind of air coming from some point to the westward or northward of the direction of the original current and sweeping across the country. The characteristic features are a sudden veer of wind, slight rise of pressure, marked fall of temperature, and a shower of rain more or less prolonged; sometimes there is a recurrence of these events. In the particular case quoted the wind dropped with the veer, and that is characteristic of many cases. There is a corresponding change in the distance apart of the isobars if due attention be paid to the small changes to be noted on the barogram, and a possible explanation has thus been

[1] "Quarterly Journal, Roy. Met. Soc.," vol. 32, p. 259, 1906, and vol. 36, p. 135, 1910.

found of the common saying that "it will not rain until the wind drops."

This furnishes an example of the importance as regards weather of the minor fluctuations of atmospheric pressure. It may also be regarded as an example of the want of numerical proportionality between the changes of the associated meteorological elements, for the effects associated with a minute change of pressure are sometimes more striking than those accompanying a great surge. An examination of the various fluctuations of pressure which are disclosed by a sensitive barograph was given in a lecture on "The Embroidery of the Barogram" at the Royal Institution on January 17, 1907.[1]

GENERAL CHARACTERISTICS OF A LINE SQUALL

A course of events of the kind indicated is quite common in westerly weather, but the sudden transition is not always characterised by a simple lull in the wind. The sweeping of the new and cold air current across the country with a line front is sometimes attended by a violent squall of wind at the moment of transition, sometimes by thunder and lightning and other indications of atmospheric instability. The phenomena are recognised in this form by the special name of "line squall," which may be understood to mean a squall of wind with rain, hail or snow, and possibly thunder and lightning, advancing across the country with a linear front so that a long narrow strip or ribbon of country, on the analogy of the French *ruban*, is affected at the same time. The name is adopted from the seaman's name for a squall that comes up with a line of cloud extending across the sky and also athwart the wind. The phenomena have probably a similar origin. In the collection of sketches at the Meteorological Office is a drawing by Mr. G. A. Clarke, of Aberdeen Observatory, showing a narrow band of cloud passing right across the sky on November 27, 1909, that can be associated with a sudden change of wind which occurred simultaneously.[2] Each line-squall has its own definite rate of advance,

[1] See Shaw and Dines on the Minor Fluctuations of Atmospheric Pressure, "Quarterly Journal, Roy Met Soc.," vol. 31, p. 39, 1905.
[2] See G. A. Clarke, "Clouds," p. 127.

from twenty to fifty miles per hour, and the advance is maintained over distances sometimes as great as 1,000 miles.

The idea of a layer of cold air advancing by displacing warmer air in front of it comes into the picture of the conflict of warm and cold air which form the basis of the working hypothesis of the polar front which we have described in Chapter V. and referred to again in Chapter X. According to the scheme of the polar front the phenomena of the line-squall are incidental to the encroachment of the cold front on the warm sector. The reader will have little difficulty in reading the language of the theory of the polar front into this chapter.

"EURYDICE" SQUALL

Line squalls are peculiarly destructive, partly on account of their violence, partly on account of the suddenness of their onset, and also because of the veer of wind. One of the best known examples is that which capsized H.M. training ship *Eurydice* off the Isle of Wight on March 24, 1878. In that case a line front of advancing cold air swept across the country from north-west to south-east; and in the south and east of England, during the early afternoon, a brilliant sunny day was suddenly transformed into wintry weather introduced by a bitter snow squall. The *Eurydice* was caught unawares with ports open and sank within sight of shore.

The changes shown by the self-recording instruments on this occasion are represented in the frontispiece (Fig. 130), which is reproduced from the "Quarterly Weather Report" of the Meteorological Office. The most noticeable feature is the great fall of temperature recorded at Kew which occurred at 4 p.m., and the same feature is noticeable at the other observatories at different times. The occurrence was the subject of papers by the Rev. Clement Ley and the Hon. R. Abercromby in the "Quarterly Journal of the Meteorological Society." It is curious that the advance of the squall line across the country from north-west to south-east is almost identical in point of time of day and relative position with the squall of February 8, 1906, which formed the subject of Mr. Lempfert's paper read

before the Royal Meteorological Society in that year. Subsequent investigation has shown that in the latter case the phenomenon, preserving its form, passed beyond the limits of the British Isles and showed itself quite prominently at the Observatory of the Puy-de-Dôme.

LINE SQUALL OF FEBRUARY 8, 1906

This example will serve as a typical line squall. It enables us to give a satisfactory indication of the general character of the phenomena. Fig. 131 shows the pressure distribution at 1 p.m., 2 p.m. and 3 p.m. with the isobars adjusted so as to indicate the changes recorded on the barograms and anemograms. It will be noticed that another squall of less pronounced type but of similar character is shown, on two of the charts, to be following the original squall. This characteristic also applies to the example of sudden lull described in Chapter IX., and may be said to be general. Whether a recovery of the initial conditions and a restitution of the original air supply takes place, or whether we have to deal with successive changes always of the same character, but coming from directions successively more veered towards northward, is at present doubtful.

Fig. 132 shows the records of the phenomena at a single station; those at Kew are here represented. It will be seen that the barometer change was very marked and that the change was accompanied by simultaneous changes in all the other elements recorded.

Fig. 133 gives the isochronous lines at successive hours for the first squall. It shows how the flood of cold air swept across the country in this case, as in that of the *Eurydice* squall, from north-west to south-east. These lines have been derived from hourly maps, each of which shows the position of the squall line as represented by the sudden changes of pressure shown in Fig. 131. When first recognised the line passed through Stornoway and lay from south-west to north-east. It advanced nearly parallel to itself

Line Squall of February 8, 1906.

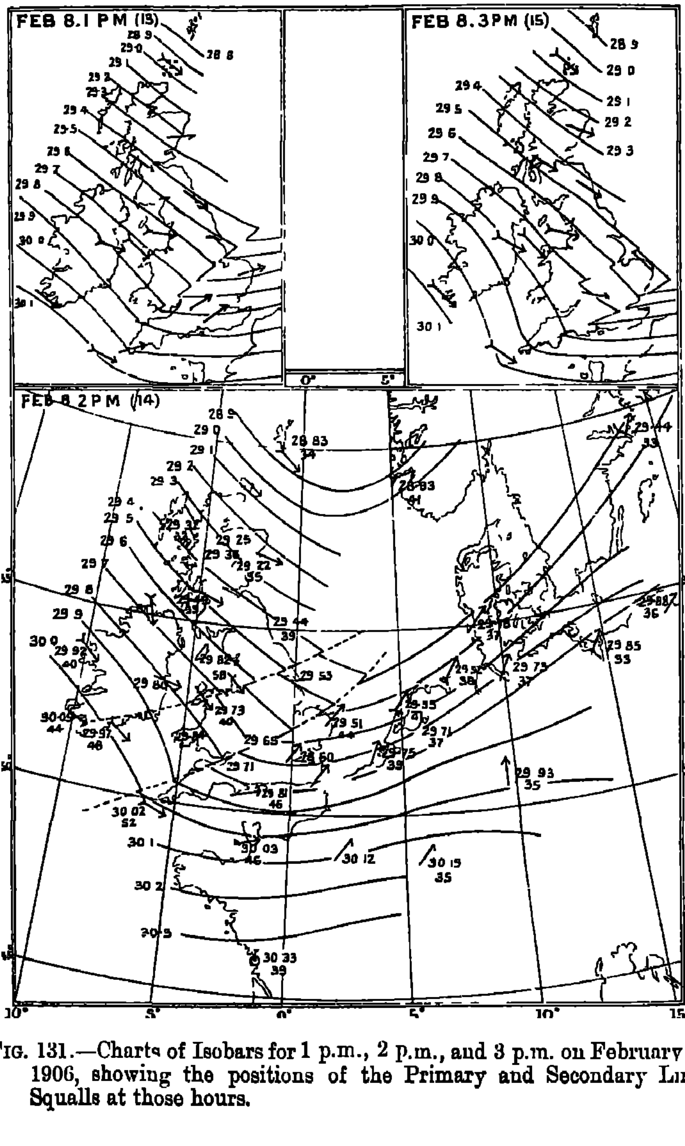


FIG. 131.—Charts of Isobars for 1 p.m., 2 p.m., and 3 p.m. on February 8, 1906, showing the positions of the Primary and Secondary Line Squalls at those hours.

RECORDS OF THE LINE SQUALL OF FEBRUARY 8TH 1906

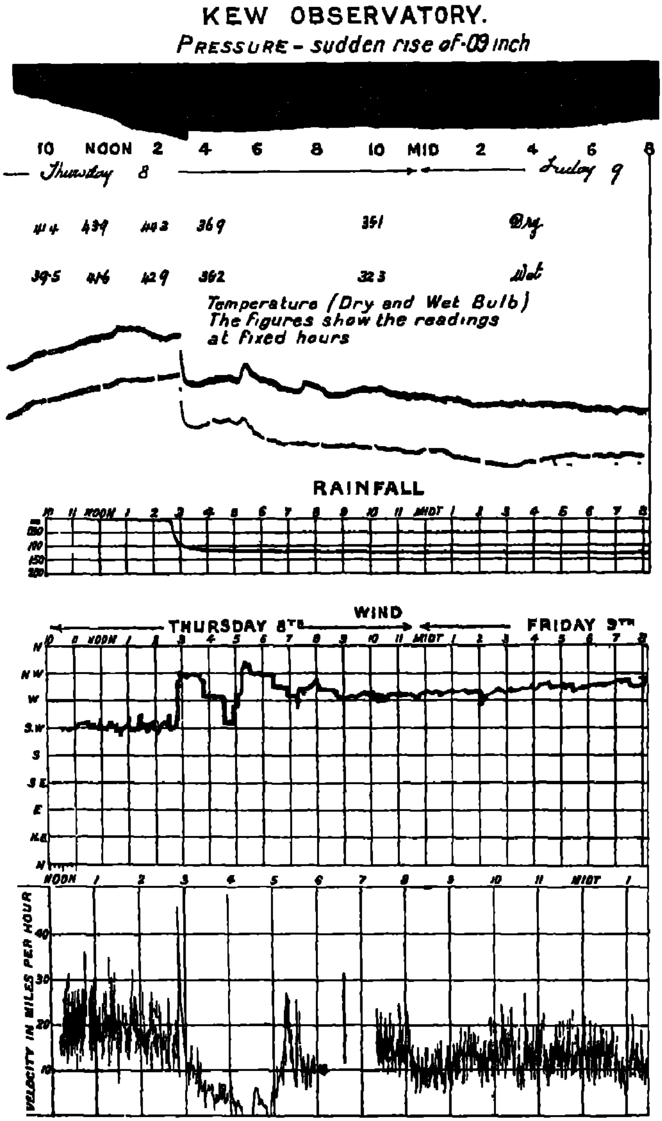


FIG. 132.

Line Squall of February 8, 1906.

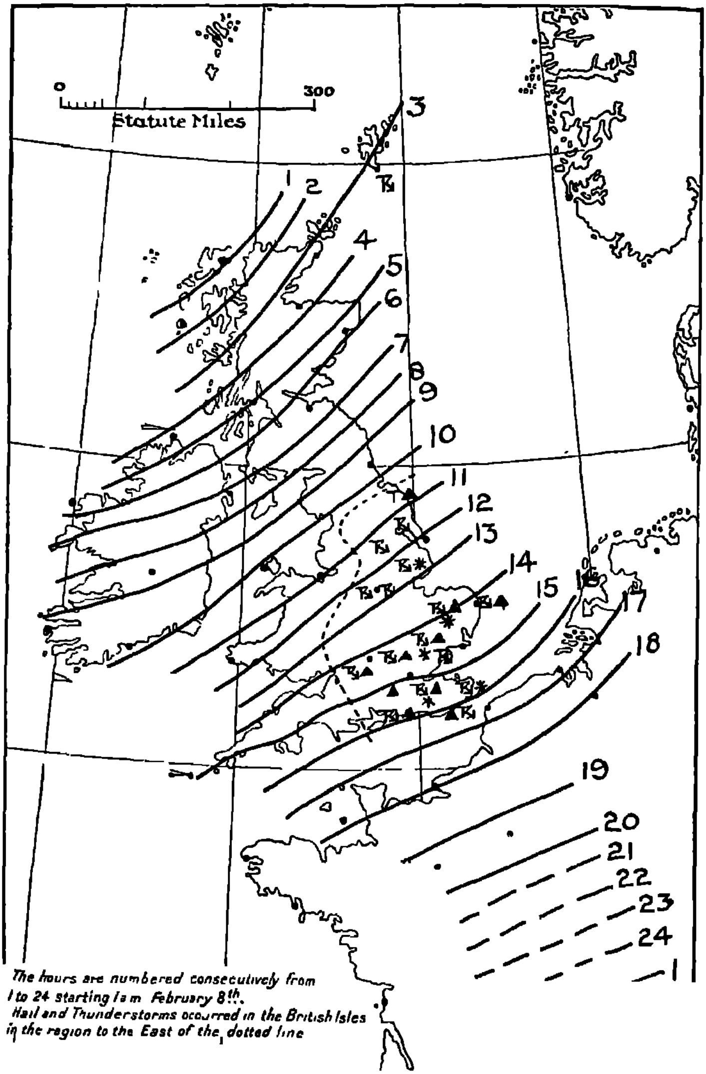


FIG. 133.—Isochronous Lines showing the Travel of the Front of the Line Squall from the Hebrides to Central France.

The region of thunderstorms in England is marked off by a dotted line

for 1,000 miles. Its characteristic sudden rise of pressure is even more clearly marked at the Observatory of the Puy-de-Dôme than at Kew.[1] On the original charts the symbols indicating the weather experienced at different parts of the country show that there is considerable variation of intensity of the phenomena along the line of front. Where the intensity was greatest thunderstorms were experienced. They are indicated in Fig. 133 by the symbol ꓘ and shown to be mostly confined to the Midland and South-Eastern counties.

LINE SQUALL OF OCTOBER 14, 1909

Another very well developed example of a line squall is that of October 14, 1909, off the East Scottish coast, to which attention was directed by Admiral Dampier, of H.M.S. *Defence*, who described the dramatic way in which at 9.30 p.m. the squall put an end to an entertainment that was in progress on his ship by carrying away the awnings and other gear. Figs. 134A and 134B represent the isobars and show the position of the squall front at 6 p.m. and 9 p.m., and Fig. 135 shows the isochronous lines for successive hours. This example, which was worked out by Mr. R. Corless, of the Meteorological Office, is specially interesting as showing the southern boundary between squall and no squall, which we must take provisionally to be the boundary of the flood of colder air. From this boundary, which crossed England at about the latitude of Holyhead, the intensity of the squall increased, and apparently it reached its maximum in the middle zone of Scotland from Paisley to Dundee.

ASCENT AND DESCENT OF AIR AT THE SQUALL FRONT

We regard the phenomena of a line squall as due to the sweeping over the country of a flood of colder and therefore denser air which gradually replaces the warmer current and substitutes for it a new current from a different direction with

[1] See "Quarterly Journal, Roy. Met Soc," vol 36, 1910, p. 136.

Line Squall. 1909. October 14, 6 p.m.

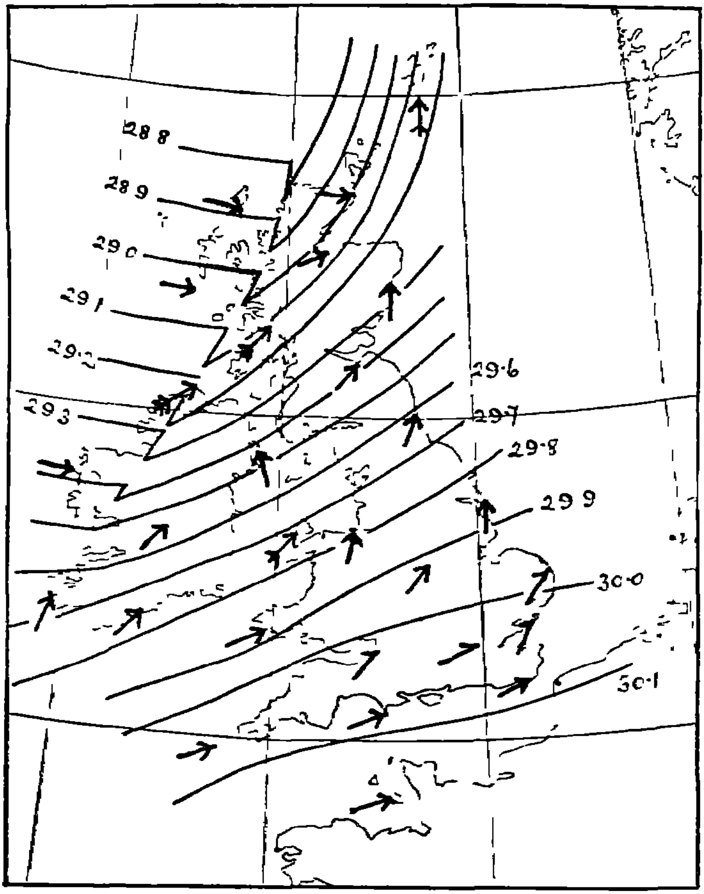


Fig. 134a.—Chart of Isobars and Winds showing the Position of the Line Squall at 6 p.m.

Line Squall 1909, October 14, 9 p.m.

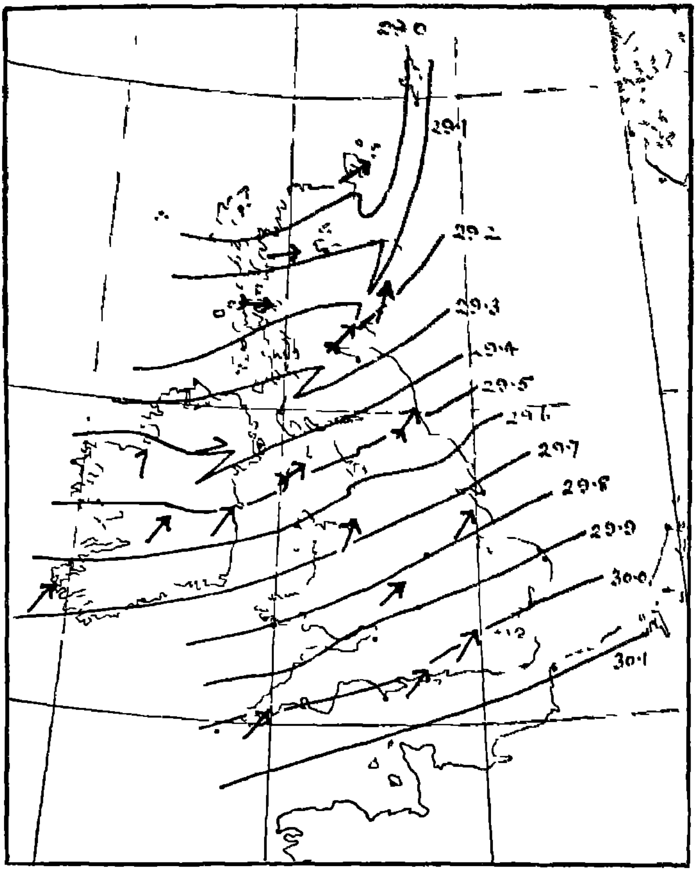


FIG 134B.—Chart of Isobars and Winds showing the Position of the Line Squall at 9 p.m.

Line Squall. 1909. October 14—15.

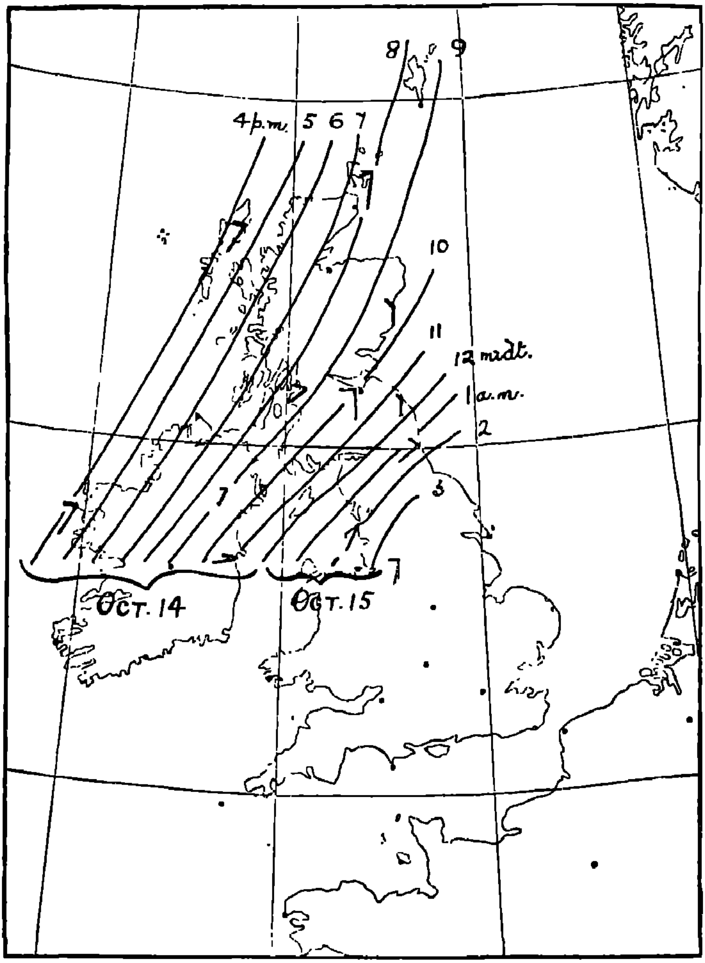


FIG. 135.—Isochronous Lines showing the Travel of the Front of the Line Squall.

The 7-shaped figures at the several stations show by the direction and length of the component lines of each figure the sudden change in direction and velocity of the wind at the passage of the squall.

a different system of pressure distribution. At the line of the squall the transition is sudden. The phenomena recall those of the advance of a bore up a tidal river, which would give in like manner a sudden increase of pressure upon a recording pressure-gauge if we may imagine it to be placed at the bottom of the river. In the case of the line squall the "bore" sweeps across the stream from one side and does not face it as a tidal bore does, but the sudden and permanent increase of pressure produced in either case (see Fig. 132) is very suggestive of analogy of cause. We may thus provisionally suppose that the sudden increase of pressure shown on the barogram is due to a sudden replacement of lighter air by denser air, at least for a certain thickness. We might compute the thickness if we knew the vertical distribution of temperature and humidity in the two kinds of air. Some attempts at computation of thickness in this manner were made for "The Life History." They are necessarily speculative, because our knowledge of the temperatures and humidities is not adequate.

The rate of advance of the line of the squall is apparently a little greater than the surface velocity of the colder air system, but not much greater. It is less than the gradient velocity in that system,[1] and may therefore be regarded as intermediate between the velocity of the wind at the surface and in the upper air of the new current system. The direction of motion of the line agrees very nearly with that of the wind in the new system, or, as we may call it, the following wind. The occurrence of rain at or about the time of passage of the line, which brings the line squalls into close analogy with the rain lines referred to in Chapter IX. shows that there is ascending air, and the ascent may be ascribed to the cold air pushing its way under the warmer current. Since we are dealing with two streams in different directions which are contiguous along a great length, we may consider the motion in a vertical cross-section independently of that along the

[1] Lempfert & Corless, "Quarterly Journal, Roy. Met. Soc.," vol. 36, 1910, p. 155.

line of junction. In the front of the line there is a large component parallel to the line; in the rear the motion is practically perpendicular to the line, and there is no component parallel to the line. The components of the two systems perpendicular to the line are apparently equal.

Dealing, then, only with the components perpendicular to the line, we get a state of affairs as represented in Fig. 136. L is the position of the sudden change associated with the squall line. The surface air in the front is warm and has a velocity v across the squall line; it is combined, as we have already pointed out, with a velocity along the line which is not represented at all in the diagram. The surface air in the

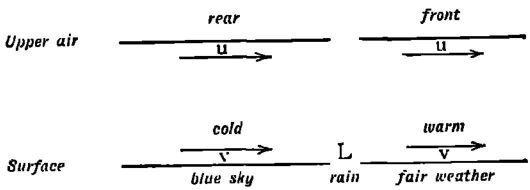


FIG. 136.—Diagram of the Distribution of Temperature, Wind Velocity, and Weather in the Vertical Section across the Front of a Line Squall.

rear is cold; it has a velocity also v. Above the front and rear at, say, a height of 1,500 feet, the component of the velocity may be taken as u, and this velocity is, perhaps, twice the surface velocity v. There is fair weather in front, blue sky in the rear, and rain, perhaps thunder and lightning, at the junction L. These phenomena travel faster than the following wind and thus gain upon the component wind in front, so that L must be supposed to move across the page and increase the rear at the expense of the front. This could be accounted for by the velocity of the cold air in the upper regions being greater than at the surface, so that in time the surface junction L would be left far behind unless L were pushed forward in front, so to speak, of its own following wind by air descending from above.

Since the velocities in the steady conditions on either side

of the line are equal, let us consider the way in which the squall gains on the wind in the front and leaves it behind in the rear. Assuming for the sake of simplicity that the line moves with a velocity which is half-way between the surface and the gradient velocity, *i.e.*, $\frac{1}{2}(u+v)$, it will gain on the surface winds at the rate of $\frac{1}{2}(u-v)$, so we may picture to ourselves the squall as marching "through the air" at the rate of $\frac{1}{2}(u-v)$, *i.e.*, gaining at that rate on the front wind and leaving the rear wind behind it, the intervening space being filled with air drawn from the cold rear supply. The descending rear air cutting under will push up the warm air of the front, and we shall thus have an ascending current in the immediate front and a descending current in the immediate rear.

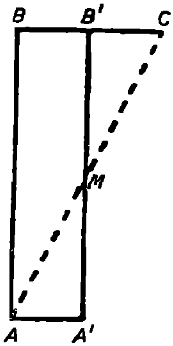


FIG. 137.—The Advance of a Cold Front as a Falling Wave.

The advance of the cold front, through the warm front before it, by the agency of the descent of cold air along the front may be illustrated by another diagram (Fig. 137) in which we deal with the relative motion only. If AB is the position of the front at any time the *air* at B is moving with the velocity $(u-v)$ and therefore gaining $\frac{1}{2}(u-v)$ upon the front. If the velocities are in miles per hour, the surface of separation between warm and cold air at B would have moved forward to C through $(u-v)$ miles; the air at A has no relative velocity, consequently, if left to itself, the motion would give rise to a new front AC, but if the air falls down the line of the front as the upper air moves forward so that the air which would be enough to fill the space B′MC actually finds itself in AMA′, the air will all have been disposed of and the front will be parallel to its original direction and will have advanced in the hour through BB′ or with a velocity of $\frac{1}{2}(u-v)$. Clearly conditions must be fortunately adjusted in order that this uniform progression of a front may be persistent. The air must fall at such a rate as to take one-half of the velocity from the air at the

top and transfer it to the ground at the front. To a certain extent the conditions adjust themselves, for if the air at C moved too fast, the fall of the cold air would become more extensive and the front would be made to travel faster. But if the flow of air at B or at A lacks uniformity, the regularity of the motion will be deranged. Such derangement may perhaps be connected with the recrudescence which is so common a feature of the phenomena of line-squalls.

The flow of air in this manner has been illustrated experimentally and discussed theoretically by W. Schmidt[1] who gives (Fig. 138) the form of a growing layer of nearly uniform thickness with a well-marked head in front as representing the march of a dense fluid along the bottom layers of a lighter fluid through an aperture of uniform height at one end. The analogy with nature in the line-squall is very close, including the sudden rise and slight relapse of pressure. What remains to be thought about is how the original aperture of march is controlled; in other words, how far upward does the discontinuity of density extend?

FIG. 138.—The Advance of a Front of Heavy Water. (Schmidt.)

The state of things may be represented as in the diagram of Fig. 139, where the line L with its rain and other phenomena is supposed to advance *through the atmosphere* at the rate of $\frac{1}{2}(u-v)$, the warm current being constantly diminished as the cold current is increased.

Perhaps we may explain the situation more clearly by considering what would happen in the case of a balloon floating near the surface in the front of the advancing line (Fig. 139). The successive positions of the balloon are indicated by the figures 1, 2, 3, 4, 5. At 1 it floats without disturbance in what we

[1] "Meteorologische Zeitschrift," vol. 28, p. 355, 1911.

may call the south-westerly current; the line advances obliquely across the current, and begins to be operative when the situation 2 is reached. The balloon is then pushed bodily upwards with the warm air by the cold current underneath, and reaches the position 3. Since the ascending air is cooled, rain, possibly hail or snow, is formed, and the balloon, carrying the extra weight, makes a descent through the boundary between the warm and cold currents, arriving at position 4. It is then

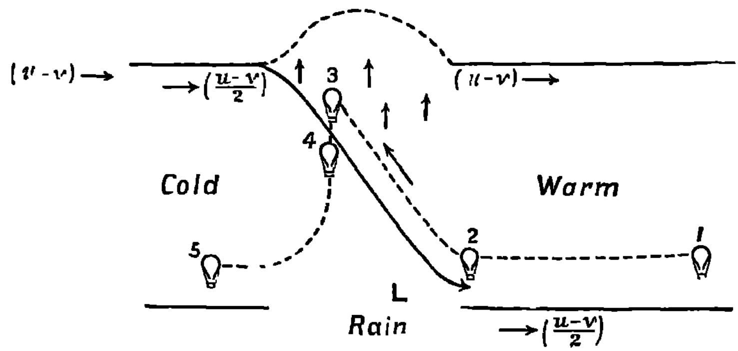


FIG. 139.—Illustrating the Motion of Air in the Vertical Section across the Front of a Line Squall.

hurried downward with the descending air, but falling further from the boundary it gets gradually into the steady region of the new air, and ultimately takes up its position at 5, in what we may call the westerly current.

It need scarcely be remarked that so simple a course is not likely to be realised in practice, because the indirect effects of the instability which occurs at the boundary may be very much complicated by irregular movements, but the suggested course tallies with all the observed meteorological conditions which are found at the transition, the sudden rise of pressure, the fall of temperature, the rain or other form of precipitation, the change of wind. The one point that has not been accounted for is the isolated violent squall that gives the

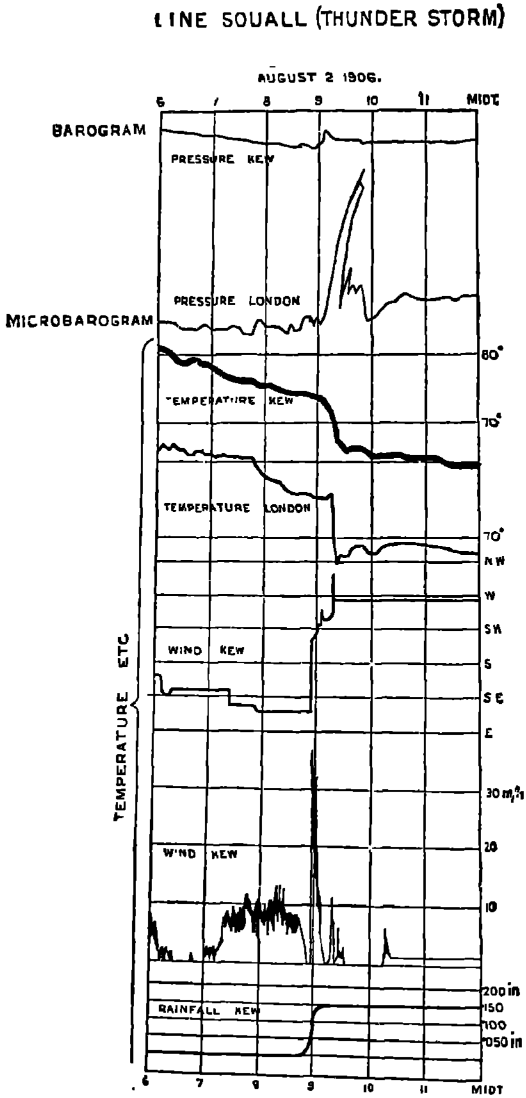


FIG. 140.—Records of Pressure, Temperature, Wind and Rainfall for the Thunderstorm of August 2, 1906.

name to the phenomena, and is sometimes very destructive. In connection with this it will be seen that in the line of the squall the isobars drawn in accordance with the barograph traces are very much contorted, so much so that in the charts they are shown as having finite angles. One isobar is therefore brought into close juxtaposition with the next at one point, and the points of close juxtaposition lie along the squall line. It is probable that under this unusual stress the dynamical system breaks down, and the air gives way under the sudden differences of pressures and an impulsive flow is thereby produced.

It will be seen that the air motion suggested in Fig. 139 would give what is mathematically equivalent to "circulation" about a horizontal axis. The phenomena of the squall have often been ascribed to a vortex with a horizontal axis, but the name is liable to convey a wrong impression. There is no whirl such as is ordinarily understood by a vortex. The air which goes up does not come down again, and the air which comes down does not go up again. There are two sheets of different air, one going up and the other coming down, and they pass one another, but there is nothing that can fairly be called an axis of rotation such as that possessed by a vortex. There will certainly be the usual vortex with a horizontal axis near the ground in consequence of the friction of the ground. Hence the actual motion is uncommonly complicated.

THUNDERSTORM OF AUGUST 2, 1906

Among other examples of line squalls or allied phenomena which have been investigated for the Meteorological Office by Mr. Lempfert we may mention the thunderstorms of August 2, 1906, which were very violent near to Guildford in Surrey, and elsewhere, and were associated with the spreading out of a layer of cold air from south-west to north-east, supervening upon very hot weather. The meteorological changes at Kew or London are represented in Fig. 140. The squall fronts on this occasion moved across the country from W.S.W. to

E.N.E. Mr. Lempfert has worked out in detail the isobars for the neighbourhood of London. He has drawn them for intervals of ·01 inch, and the result is represented in the paper before the Royal Meteorological Society.[1] These are somewhat different in shape from those of a typical line squall. They show clearly some local circulation which is at least not noticeable in other cases. The difference between the two is apparently a matter of local conditions.

SQUALLS OF FEBRUARY 19—20, 1907

For the occasion of February 19—20, 1907, which has already been referred to in another connection (see Fig. 15), Mr. Lempfert has also worked out the sudden changes of the trough line, and has shown that a line squall of the regular type crossed this country on that occasion. Upon passing across to Germany it developed into a series of isobars running parallel to each other with a line of great gradient of temperature crossing the isobars of 28·8 inches to 29·2 inches very obliquely In the region of great temperature-gradient, thunderstorms were developed.

THE TROUGH LINE OF CYCLONIC DEPRESSIONS

There is some ground for thinking that these squall fronts, representing the advancing boundary of a new air supply, extend to the centre of a depression, and they are often indicated upon synoptic charts as the axial line of a secondary or a rain-line. Not infrequently they occur upon the abrupt termination of the rapid fall of the barometer. The course of events seems to be that the fall of the barometer is suddenly arrested and reversed; the pressure thereafter remains more or less steady for some hours, a further fall subsequently taking place. The course followed by the barometer is very well illustrated by the record for Holyhead for

[1] "Quarterly Journal, Roy. Met. Soc.,' vol. 36, p. 141, 1910.

August 31—September 1, 1908 (Fig. 141), which was obtained during the passage of the stormy depression which preceded the British Association meeting of that year. It appears that in these cases it is a new air which brings the fall of the barometer to a sudden termination and produces a little rise. Very frequently the squall line is actually the trough line, and no further decline of pressure takes place after the passage of the squall; then the phenomena of the line squall become the phenomena of the passage of the trough. The worst winds of a gale are often experienced in

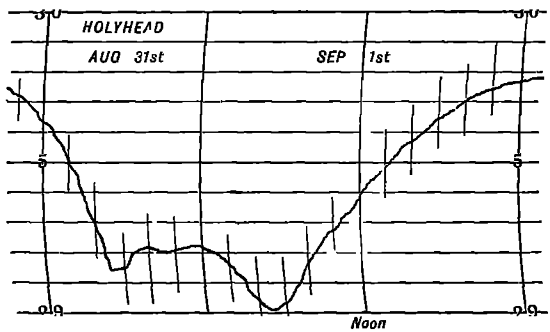


FIG. 141.—Typical Record of Pressure during the Passage of a Cyclonic Depression.

these circumstances and make the passage of the trough a period of special consideration.

Why the trough line should also be a squall line is at present a question upon which speculation is hazardous. The circumstances suggest that the cutting in of the more westerly or northerly current is determined by the reduction of pressure in the broad southerly or south-westerly stream, and perhaps it spreads from where the pressure is lowest There is little doubt that the actual life history of the depression is in some way mixed up with these phenomena, but the precise manner of it is at present undetermined.

PRESSURE VARIATIONS IN AN EASTERLY CURRENT

I know of no example of a line squall in an easterly current, that is in the north-eastern part of a cyclonic depression. From an investigation of the weather chart for 6 p.m. on October 23, 1909, it appeared that the phenomena of a line squall, or a secondary, were prolonged beyond the centre of the depression and were represented in the northern part of it by a disturbance which took the form of a very sudden fall of pressure of about 0·1 inch at Leith, where the wind, though light, was from the East (Fig. 142). The matter interested me because for a time the 6 p.m. report telegraphed by the observer was supposed to be 0·1 inch in error on the authority of the barogram; but examination proved that an inaccuracy of a few minutes in the timing of the trace would have just made the difference. The meteorological conditions on that occasion were very complicated and the barogram of Aberdeen as well as that of Leith showed marked fluctuation. The barograms for the southern part of the depression showed the characteristic notch of a line squall, indicated at 2 p.m. in the reproduction of the barogram for Scilly (Fig. 143). Mr. Corless has made out for me a series of charts to represent, hour by hour, as nearly as possible, the pressure distribution represented by the

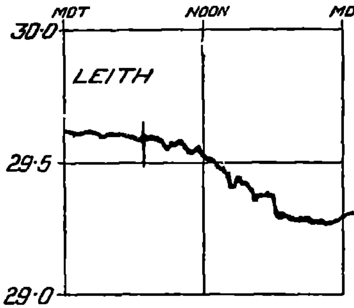


FIG. 142 Barogram for Leith. October 23, 1909.

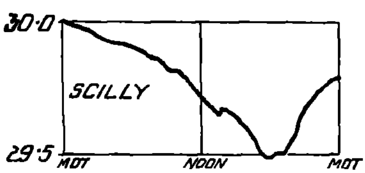


FIG. 143.—Barogram for Scilly. October 23, 1909.

barograms in this complicated case, as a solution of the problem of translating into synoptic charts the information given on the barogram in all its details. The solution for 6 p.m. is given in Fig. 144. It is, however, found to be very difficult to give any reasonable representation of the effects observed north of the centre. Nothing corresponding with a line-squall is observable, but some vigorous oscillations are represented. They invite further investigation but do not affect the explanation of the phenomena south of the centre.

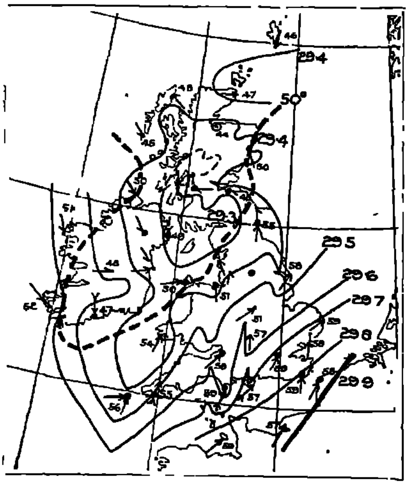


FIG. 144.—Chart showing in detail the shapes of Isobars over the British Isles at 6 p.m. on October 23, 1909, as inferred from the Automatic Records of Barographs.

I am accordingly still of opinion that the phenomena of the line-squall are due to the flooding of the surface with air from some westerly or northerly point, or in the most recent language, the invasion of the cold polar front.

THUNDERSTORMS

It is clear that the undercutting of the warm surface layer of southerly air by a more westerly or northerly one will create the conditions which we have stated to be necessary for the causing of instability in the atmosphere. We have the flow downwards of the air behind the squall-front and the ascent of the air that is displaced. Either of these may account for the production of instability in that region attended by violent showers, hail, and possibly thunder and lightning. These are the physical conditions for the formation of thunderstorms,

and I give an example of the storm of June 1, 1908 (Fig. 145), which was attended by a violent squall of wind that destroyed the east end of Bushy Avenue. It differs from a line-squall of the type which we have been considering in this chapter by being preceded and followed by practically calm air, so that isobaric charts give us very little information. In other respects all the phenomena of the line-squall are apparent, and presumably the cause is of a similar character.

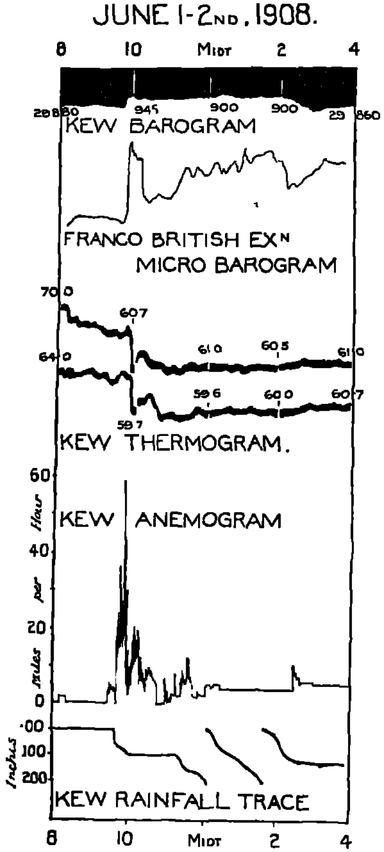


FIG. 145.—Autographic Records for Kew and London during the Destructive Thunderstorm of June 1—2, 1908.

Phenomena analogous to those which we have considered under the heading of "line-squalls" occur in nearly all depressions, and their investigation shows that attention to small details in the march of the barometric trace would, in certain circumstances, furnish an aid to precision in forecasting. We have approached the subject from the point of view of the physical explanation of the phenomena. In the meantime from the point of view of precision in forecasting, M. Durand Gréville has taken up the consideration of what we should call V-shaped depressions, which also represent sudden changes of wind, and

are in many ways similar to line-squalls. In treating of his subject he speaks, in fact, of the *ligne de grain,* which is the equivalent in French of our term line-squall, while his *ruban de grain* is easily expressed as applied to the phenomena of line-squalls. M. Durand-Gréville's work was highly commended by the adjudicators in a competition in forecasting held in 1905 in connection with the International Exhibition at Liège.

The fundamental point of his argument is that the smooth run of the isobaric curve with the associated continuous changes in wind and other elements is often not followed in actual experience; and that if isobars are carefully and correctly drawn for sufficiently close intervals they will show the following phenomena arranged in lines running more or less radially from a low pressure centre over 1,000 miles or more: first, a more or less rapid increase of rate of fall of pressure, followed by a sudden rise, and then a reversion to the ordinary curve. These changes take place simultaneously along a line (*ligne de grain*), which sweeps across the country like an advancing wave, with a more or less constant direction and rate of advance. He calls the line of minima which precedes the sudden rise the *couloir de grain,* the stretch of country where the sudden rise gives isobars much closer together than elsewhere the *ruban de grain.* In this region, as the *ligne de grain* sweeps over the country, there are squalls followed by rain showers, which may be of different intensities at different parts of the line. In some parts the energy may develop a thunderstorm, in others light rain only, or the instrumental indications for pressure and temperature may be the only indications of the passage of a *ligne de grain.* The trace of the sudden increase of pressure, which we have recognised as a characteristic feature of a line squall, is called the *crochet d'orage,* corresponding with the German term *Gewitternase.*

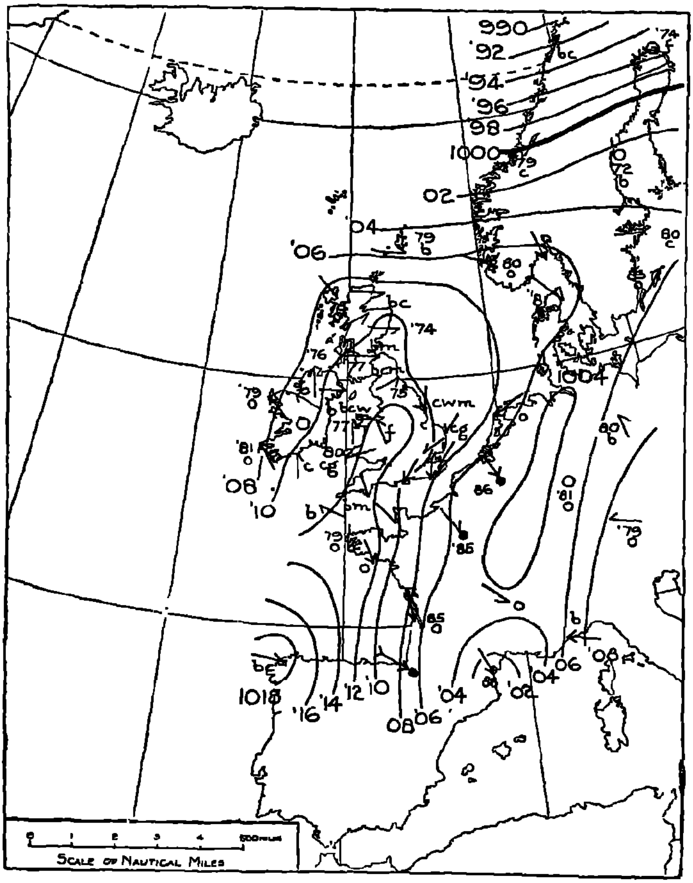
M. Durand-Greville thus suggests definite weather phenomena as associated with some of the elements of the embroidery of the barogram, usually the sudden, though

slight, variations of pressure, and these travel across the map with such regularity that they permit the forecast of the hour at which the line will reach a specified place. He has made some remarkably accurate forecasts of the occurrence of thunderstorms in France by the application of this method.

Apart from its direct application in this manner it leads us to examine the question of the arrangement of weather phenomena with reference to the pressure minima. In the cases illustrated by M. Durand-Gréville these phenomena are not characteristic of a quadrant or sector of a circle, but of a belt of more or less uniform breadth, running from the minimum as a radial band for a very great distance—far beyond the region of closed circular isobars.

In order to indicate more clearly the existence and position of these *lignes de grain*, M. Durand-Gréville recommends the use of a smaller interval for consecutive isobars in a synoptic chart than the 5 mm. interval which is customary on the weather maps for which the metric system is employed. He is, indeed, in favour of drawing isobaric lines for each millimetre. In order to illustrate this suggestion I have had maps prepared, in which the steps of pressure are one five-hundredth of the C.G.S. atmosphere, equal to 1·5 mm., or 2,000 dynes per square centimetre, or 2 millibars as we now call them. This scale of pressure measurement was recommended by a committee and approved by the Council of the British Association, and also by the Meteorological Council in 1904, in response to a request from the committee of Section A, at the instance of the International Meteorological Committee which met at Southport in 1903, for the adoption of a uniform system of units for pressure measurements. The report was presented to Section A in 1904, but no action was taken with regard to the suggestion. The subsequent action has already been referred to, and it may be noted that intervals of 2 millibars, employed in Figs. 146A and 146B, are the intervals adopted for the charts of the Daily Weather Report, British Section (Fig. 4). The method is used for the remaining charts of this chapter, in order to illustrate its applica-

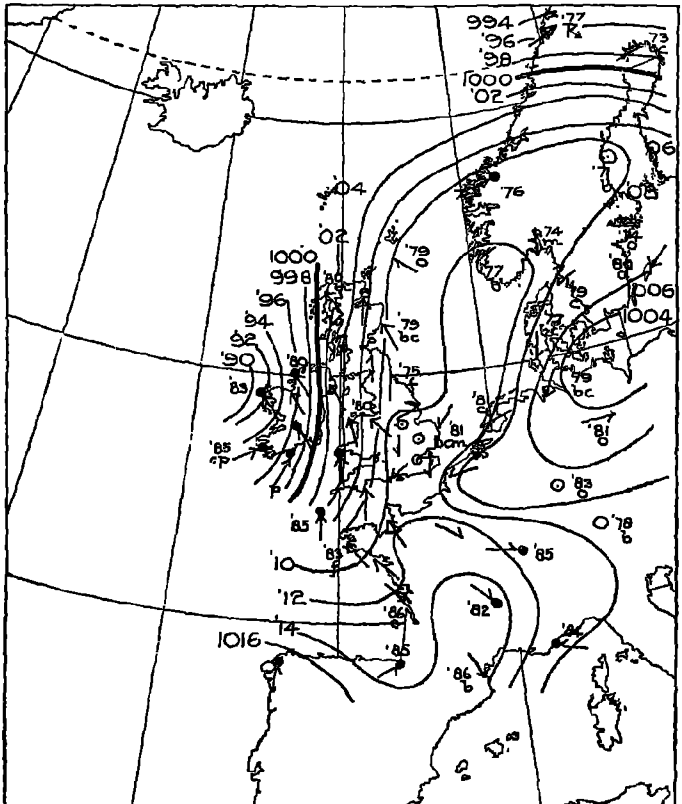
1892. November 1, 8 a.m.



Pressure is shown in thousandths of a C.G.S. atmosphere (now called millibars), Temperature in the tercentesimal scale with the first figure, 2, omitted.

FIG. 146A.—Chart showing the Advance of a "Ligne de Grain."

1892. November 2, 8 a.m.



Pressures in millibars, Temperatures in the tercentesimal scale with the first figure, 2, omitted.

FIG. 146B.—Chart showing the Advance of a "Ligne de Grain."

tion. In preparing them the observations subsequent to 1904 have all been corrected for the deviation of the value of gravity from that at latitude 45 degrees.

An example (Figs. 146A, 146B), which is referred to in the report of the Commission of judges of the Liège competition, is shown in the maps for 8 a.m. November 1 and 2, 1892. It illustrates a *ligne de grain* in which the variations of pressure are much less abrupt than in the case of the line squalls to which we have referred. There is a *couloir de grain* represented by a long strip of low pressure extending from a depression north of the Baltic to the Mediterranean, and the *ruban de grain* is shown by the compression of the isobars between the *couloir* and the tongue of high pressure extending from Spain over the Bay of Biscay. At the end of this high-pressure region there is another low-pressure region indicated by the southerly winds in the west of Ireland. This was made the basis of the forecast by M. Durand-Gréville of another *ruban de grain* following the first. Its development is shown by the north-and-south isobars over the British Isles in the map for November 2 (Fig. 146B). In this country we should have regarded it as denoting the approach of a new depression, and doubtless our ideas would have tended towards a circular depression rather than an elongated area of low pressure signified by calling it a *ruban*. It makes, however, for progress that we should be reminded from time to time that the ideas which govern our system of forecasting are susceptible of modification, and the question as to whether a circular depression or a *ruban de grain* has the better claim to be regarded as the normal type is worth discussion. As regards the prognostication of the incidence of rainfall, the *ruban de grain* is a more effective idea than the circular depression. We leave the reader to translate M. Durand-Greville's ideas into the language of the polar front. It can be done without the use of a dictionary and not more grammar than is included in Chapters V. and X.

MINOR FLUCTUATIONS WITHOUT APPARENT INFLUENCE ON THE WEATHER

We have seen that many striking features of weather are associated with very small changes in pressure, such as may be included in the general title of the embroidery of the barogram. But the converse proposition is not true, we can find a number of cases in which very curious fluctuations of pressure are unconnected with corresponding changes of weather, or to speak more accurately, whatever correspondence there may be has not yet been identified. In support of this statement we may refer particularly to the wave-like variations of pressure which are shown on the microbarograph, some examples of which are given in the paper which described that instrument.[1]

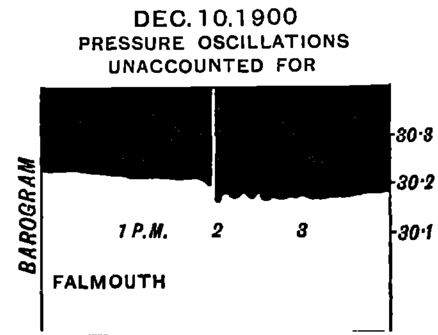


FIG. 147.—Oscillations of the Barometer at Falmouth, December 10, 1900.

The usual period for such wave-like oscillations is ten minutes to twenty minutes, and an oscillation with that order of frequency seems to be natural to our atmosphere. The period of ten minutes with a gradually diminishing amplitude is clearly shown in the reproduction of the mercury-barogram of Falmouth for December 10, 1900 (Fig. 147). A longer period of about forty minutes is shown in the transient oscillation at Eskdalemuir on March 6—7, 1918 (Fig. 148), which manifests itself not only in the pressure, but also in the direction and velocity of the wind.

Such periodic variations in wind are sometimes noticed when

[1] " Q. J. Roy. Met. Soc.," vol. 31, p. 39, 1905.

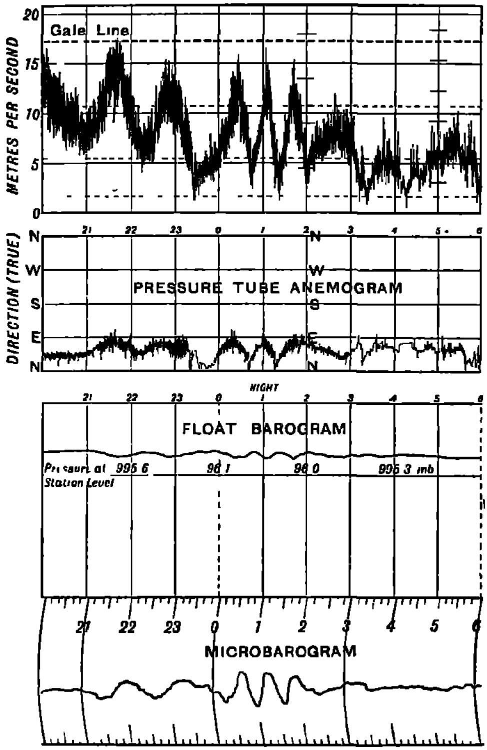


FIG. 148.—Squalls and Oscillations of Pressure at Eskdalemuir, Mar. 6—7, 1918.

For another example see "Nature," vol. 111, p. 598, 1923.

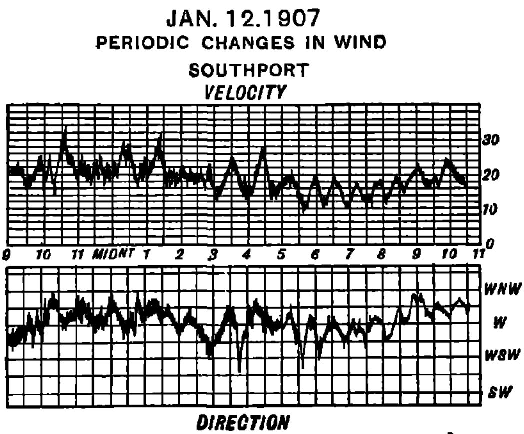


FIG. 149.—Oscillations of the Wind at Southport, January 12, 1907.

no corresponding variation in the pressure has been noticed. The record at Southport for January 12, 1907, appears to be a case in point (Fig. 149). An endeavour to decipher the explanation of these periodic changes from the vector changes in the wind is given in a paper before the Royal Meteorological Society.[1]

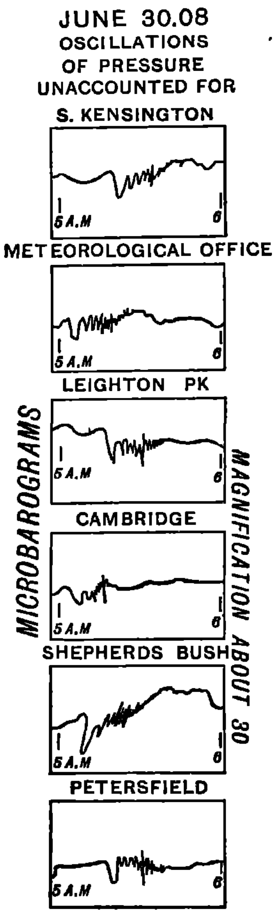


FIG. 150. — Oscillations over the Region from Cambridge to Petersfield, June 30, 1908.

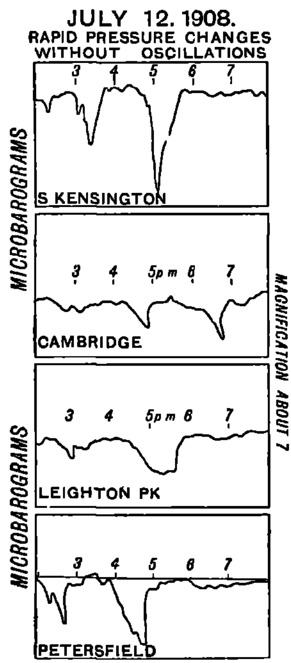
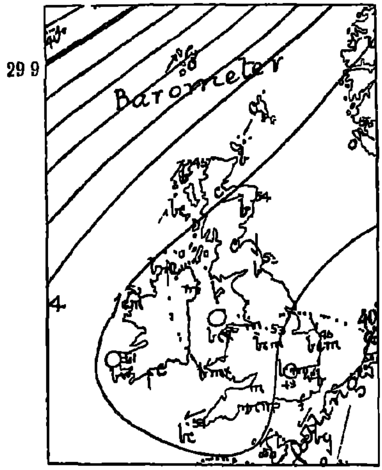


FIG. 151 — Deep Depression of Small Area. Depressions occurred during thundery weather, but locally there was nothing more than a few drops of rain, July 12, 1908.

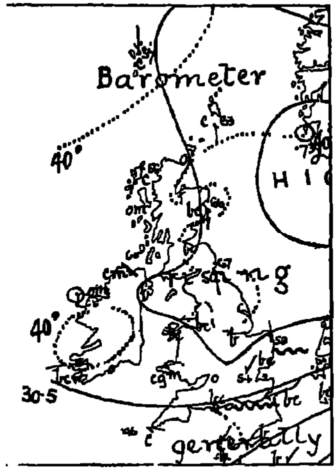
What it is that actually forms the oscillating system in these cases is a question which excites curiosity which is at present

[1] "Q. J. Roy. Met. Soc.," vol. 36, p. 25, 1910.

1910 March 30, 7 a.m.



1910 March 31 7 a.m.



1910 April 1, 7 a.m.

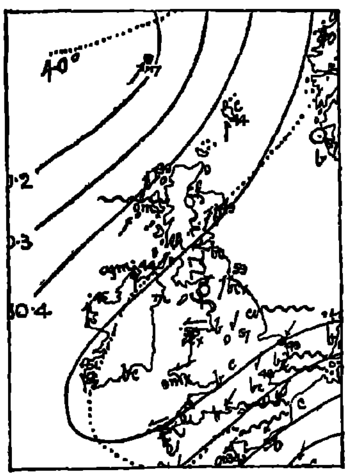
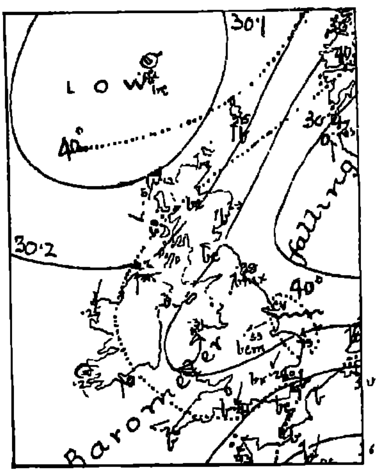
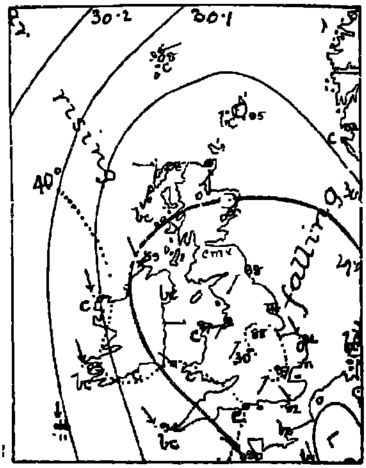


FIG. 152E.—Spring Anticyclone of 1910 (*continued*).

1910. April 2, 7 a.m.



1910. April 3, 7 a.m.



1910 April 4. 7 a.m.

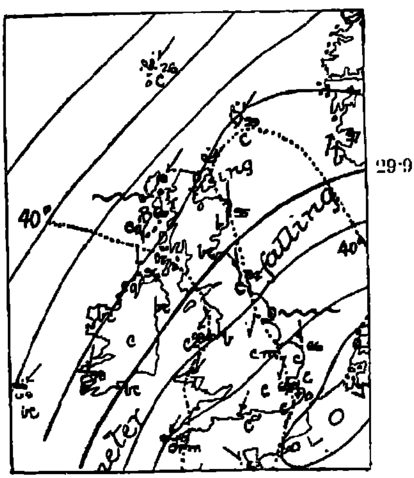


Fig. 152f.—Spring Anticyclone of 1910 (*continued*).

conspicuous example of anticyclonic conditions over that area in recent years, giving an isobar of the remarkable height of 31·3 inches.

Still higher pressures were shown further to the east than the limit of the map. Note the differences of weather and of temperature within the region of pressure above 30·8 inches.

A SPRING ANTICYCLONE

We may next pass under review the series of maps representing the notable spring anticyclone of 1910, which gave generally fair weather over the British Isles from March 19 to April 2 (Figs. 152A—F. It began with the advance of high pressure from the Atlantic on March 18, it was central over the British Isles on March 25, and again on March 29 after a disturbance, threatened from the Icelandic region, had receded. It finally gave way to a shallow low

SPRING ANTICYCLONE OF 1910.

General Characteristics of Weather.

Date.	England.	Scotland.	Ireland.
March 19 .	Cloudy.	Overcast.	Overcast.
,, 20	Fine to overcast (r).	Cloudy.	Cloudy (f).
,, 21	Cloudy.	Cloudy (r).	Cloudy (r).
,, 22	Fine.	Fine to overcast.	Fine (r).
,, 23 .	Fine to overcast.	Overcast.	Overcast.
,, 24	Overcast.	Fine to overcast.	Fine to overcast.
,, 25 .	Overcast.	Overcast.	Overcast.
,, 26 .	Fine to overcast.	Overcast.	Overcast.
,, 27 .	Fine to overcast.	[Cloudy (r)].*	[Rain].*
,, 28 .	Fine (f. r).	Fine.	Fine.
,, 29 .	Fine (m).	Fine.	Fine (f).
,, 30 .	Fine (m).	Fine.	Fine (m).
,, 31 .	Fine to cloudy.	Cloudy (f).	Cloudy (m).
April 1 .	Fine to overcast.	Fine to overcast.	Cloudy (m).
,, 2 .	Fine.	Fine.	Cloudy to overcast (r).
,, 3 .	[Cyclonic depression.]		

The letter (r) indicates that rain was reported at 7 a.m. from one or more stations; (m) mist, and (f) fog.

* On this occasion these countries were under the influence of a cyclonic depression centred beyond Iceland.

pressure area coming with strong north-easterly wind from the Continent. We have thus fifteen days of continuous anti-cyclonic weather, and on p. 367 I have indicated quite briefly the weather of each day in each of the three kingdoms.

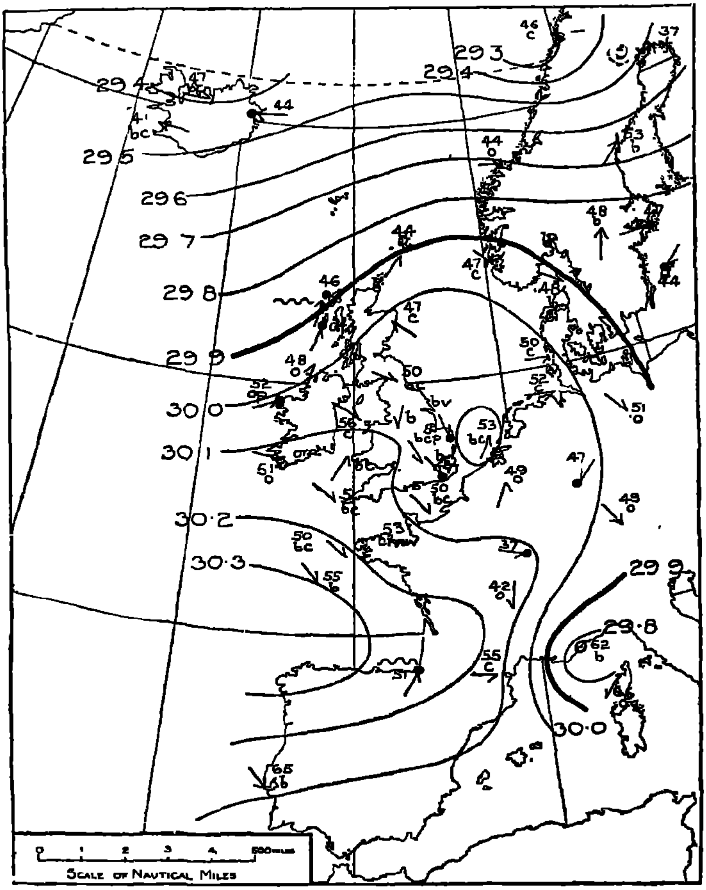
It will be seen that an overcast sky occurred frequently during the period of the anticyclone, and that on some of the days rain was reported, although the amounts were in all cases small.

ANTICYCLONES WITH RAIN

We may refer also to the map for 8 a.m. of April 9, 1908, already reproduced in Fig. 21, where rain is indicated as falling at eight stations within a large anticyclone. No doubt in this case the contortions of the 30·1 inch isobar enable us to attribute the rainfall to irregularities of pressure. My contention is that such irregularities of pressure are possible and not infrequent within the precincts of a region definitely anticyclonic, and the contention is borne out by the map for 8 a.m. on May 23, 1908 (Fig. 153), which shows a little area of relatively low pressure, 30·0 inch, with associated rain, included within a pronounced anticyclonic region bounded by the isobar of 29·9 inch. A still more striking instance is to be found in the map of June 27, 1908 (Fig. 154), which shows an anticyclonic isobar enclosing the central region of an extensive anticyclone, with rain at three stations within the central isobar and at one within the next lower step of pressure. This chart is included in the series representing a summer anticyclone referred to on p. 172.

It may be easily allowed that the rainfall in these cases is not large; sometimes it appears to be only the rainfall of a wind striking an elevated coastline and producing rain over the districts which offer obstacles to the advancing current; but in the case represented, the rain at Nottingham cannot be attributed to such mechanical action. It might be due to the gradual ascent of the moist air of the surface in consequence of eddy-motion in the

1908. May 23, 8 a.m.

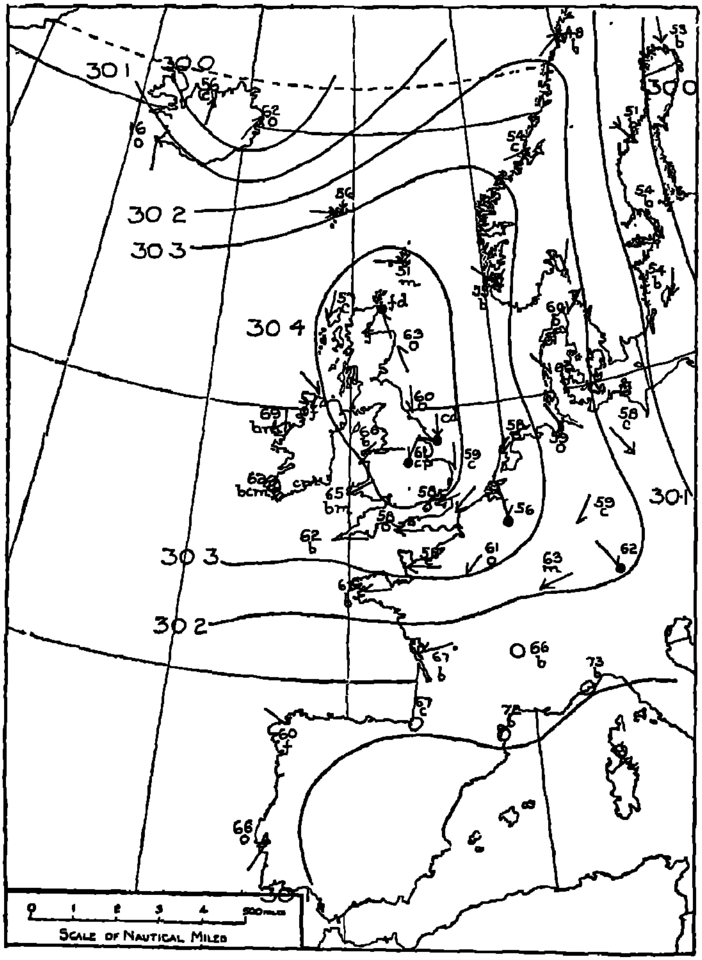


CONVERSION TABLE.

In.	Mb.	In.	Mb.	In.	Mb.
29·4	995·6	29·8	1009·1	30·1	1019·3
29·5	999·0	29·9	1012·5	30·2	1022·7
29·6	1002·4	30·0	1015·9	30·3	1026·1
29·7	1005·7				

FIG. 153.—Rain within the Precincts of an Anticyclone.

1908. June 27, 8 a.m.



Conversion Table.

In.		Mb.	In.		Mb.	In.	Mb.
30·0	.	1015 9	30 2	.	1022·7	30·4	1029 4
30·1	.	1019·3	30·3	.	1026·1		

Fig. 154.—Rain in the Central Region of an Anticyclone.

current coming down from the north[1] but in any case, the slight fall of rain is sufficient demonstration of the absence of descending air in the locality affected. We must allow any kind of weather within the closed curve of an anticyclonic isobar, provided it is not of a violent character.

FINE WEATHER ANTICYCLONE

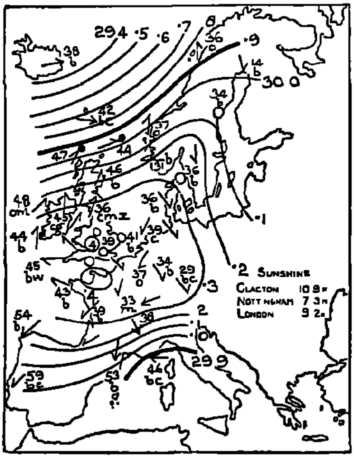
We have already had under consideration (Figs. 70A, 70B) an example of a summer anticyclone, the generally fine weather of which was somewhat marred by rain.

I propose to give one other example of an anticyclone, that of the week from March 24 to March 30, 1907, which was associated with as fine weather as can be experienced in these islands. In consequence of the stillness of the atmosphere, the weather was exceptionally continental in its character. The mean maximum and minimum temperatures for the week at the stations in the line of section, as well as the extreme temperatures for the week and the duration of sunshine expressed as percentages of the maximum possible, are shown in the " meteorological section " across the British Isles which is reproduced from the Second Annual Report of the Meteorological Committee (Fig. 156). An extreme difference of as much as 44° F. is shown between the extreme temperature of day and night near the east coast. The differences between the coastal stations and the inland stations are very noticeable in the section.

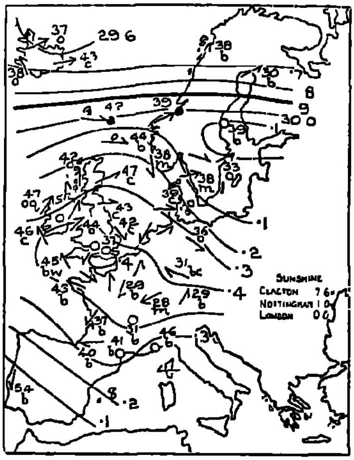
The weather charts for 8 a.m. of each day of this week of fine weather are represented in Fig. 155. The duration of sunshine registered day by day at Clacton, Nottingham and London is marked on the charts.

[1] The formation of rain in a northerly current coming down the North Sea, such as that of Fig. 154, and so passing gradually with eddy-motion over water successively warmer was often in evidence in the reports of weather from the western front during the war.

1907. March 24, 8 a.m.



1907. March 25, 8 a.m.



1907. March 26, 8 a.m.

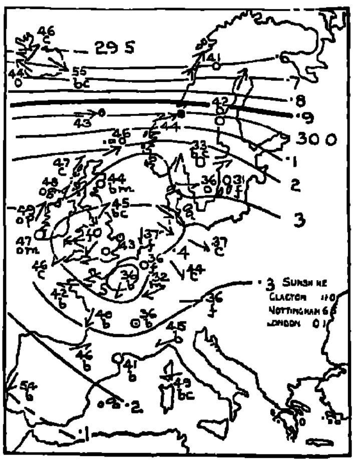
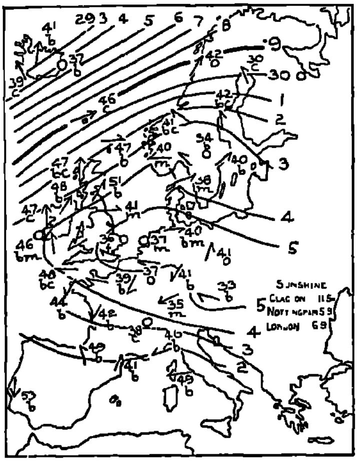
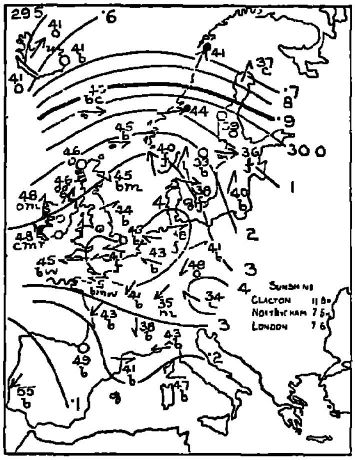


FIG. 155.—Week of

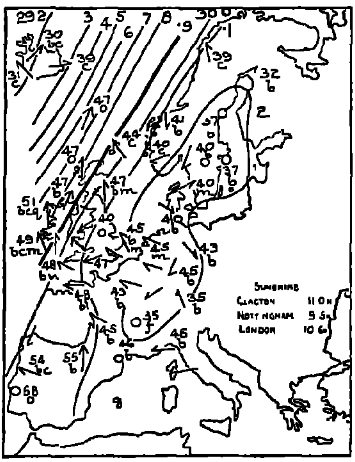
1907. March 27, 8 a.m.



1907. March 28, 8 a.m.



1907. March 29, 8 a.m.



Fine Weather in 1907.

Section West to East across the British Isles showing Temperature and Sunshine during Cloudless Weather, March 24—30, 1907.

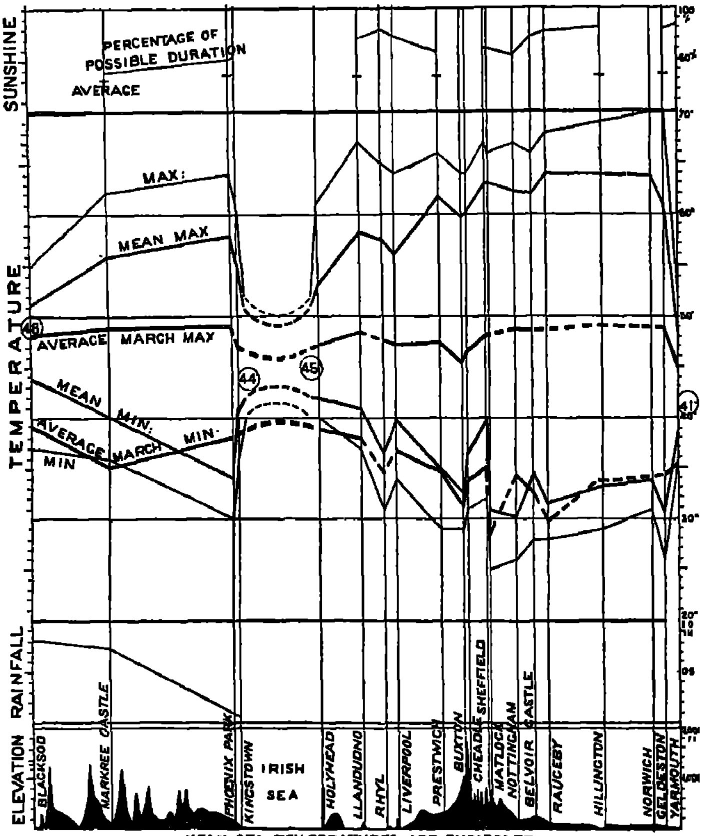


FIG. 156.—Fine Weather Anticyclone.

The relief of the country along the line of the section is shown by the black profile at the bottom of the diagram with a scale of feet, along the right-hand side. The positions of the stations are marked by vertical lines with the names against them. Particulars as to sunshine mean and extremes of maximum and minimum temperatures, with averages for comparison, are shown by lines crossing the diagram with a scale of temperatures at the side.

DROUGHTS

In spite of the fact that occasionally anticyclones may manage to harbour a little drizzling rain the chief characteristic of anti-cyclonic weather is its dryness, and drought is fairly regarded as the natural accompaniment of a prolonged anticyclone. Among the various empirical rules for forecasting which have been communicated to me was one to the effect that it would not rain in this country if pressure exceeded 30·3 inches or 1,026 millibars. This rule I kept in mind for some time, intending to confute the principle; the map for 7 a.m. of September 4, 1911, presses it rather hard; but the war supervened before I had found suitable examples, and I leave the problem to be dealt with by the reader either as a physical principle or as an empirical statement which can be contradicted or verified by experience. In any case, rain with high pressure is rare, and relatively high pressure in the neighbourhood of depressions is often accompanied by brilliant weather. We may accordingly regard the occurrence of drought as being associated with the persistence and recurrence of high pressure over us.

The year 1921 has become notorious for its drought that went almost to the extent of dearth. The southern and eastern counties of England, which may almost be said normally to have the "*optimum*" sequence of rainfall for crops and other purposes, had only half their normal quantity during the year, and have found that to be distinctly insufficient. The drought went on with very few periods of relaxation throughout the year, and we therefore have a more favourable opportunity of studying the conditions for drought than ever before since weather maps began.

The conditions will be best understood by reference to the maps of pressure and wind for January and July in Figs. 9, 10, and 11. Taking first the July map, it will be seen that the great Atlantic anticyclone becomes very extensive in the summer, and its outer margin, as represented by the last closed isobar (30·0 inches), just reaches the Channel, the next isobar, 29·9, which clearly belongs to the anticyclone on the north side and very nearly completes

the circuit, crosses north of Ireland. Hence, the British Isles lie just on the fringe of the great anticyclone; its eastern ridge runs a little south of us through the north of Spain and middle France to Central Europe. There is, moreover, a ridge of high pressure east of the Scandinavian peninsula which connects the extension of the Atlantic anticyclone with a less well-marked high pressure over the polar regions. We may at any time get within the influence of this line of high pressure either by the extension of the Atlantic "high" a little to the north or by the accentuation of the ridge of high pressure over the Baltic. In 1921 a ridge from the mid-Atlantic was frequently over us and joined the Baltic "high"; thus a line of high pressures with a consequent *corridor of fine weather* was very frequent in the maps, sometimes as an obvious extension from the south-west, sometimes as an equally obvious extension from the east, and sometimes accentuated sufficiently to form a local high pressure, but always with a ridge to south-west or north-east.

So the anticyclonic weather came to us as a local expression of one of the features of the general circulation of the atmosphere round the Asiatic low on the one side and round the Greenland low on the other. Such a condition is always practically in existence, but the ridge is generally to the south of us and our region in the north is generally subject to frequent invasion of travelling low pressures of the Iceland region. In 1921 they existed in their usual numbers, but they kept to the north and seldom managed to approach the Channel. They gave more than the usual allowance of rain to the north of Norway, but left our southern and eastern districts so dry in the summer and autumn that a water-famine was threatened, and in part realised.

In winter, as represented by the map for January (Fig. 9), the conditions differ from those of July in important details, and yet present some analogy. There is still a chain of high pressures from the middle of the Atlantic to Central Europe, but the continuation of the chain is not northward *viâ* the Baltic to the North Pole, as in July, but eastward direct to a great centre of high pressure in Central Asia. Westward there is continuous high

pressure over the United States connecting with the anticyclone of the Eastern Pacific and beyond that to the western side of the great Asiatic anticyclone. Hence, in winter, as in summer, there is a corridor of fine weather across Europe from the middle Atlantic, and it may be continued round the world between the parallels of 30° N and 50° N. Its normal position is over Spain, more than 600 miles south of the British Isles, hence, in winter still more than in summer, the British Isles are generally on the northern side of the corridor, and therefore more subject to the changes of passing cyclonic depressions than they would be on the corridor itself with its typically fine weather. But the conditions are sufficiently elastic for the corridor to shift its position northward so that its ridge-line lies over Britain. Then our southern districts get the easterly wind, appropriate to the south side of the corridor, coming direct from the frozen ground of Europe and Asia. They provide a spell of cold weather for the southern districts, while the more northern districts have the advantage of the westerly airs of the northern side of the corridor. Hence, in winter, drought is usually associated with freezing weather in southern districts, the reverse of the effect in summer, when the Continent offers an effective arrangement for warming the air that passes over it.

In any case, the examination of the causes of droughts invites the study of the corridors of fine weather which connect the great centres of high pressure in summer and in winter, the variations of position to which they are subject, and the variation of intensity in different parts.

This may lead on to the study of the disposal of the air, which is lifted to the higher regions of the atmosphere in the course of the formation of rain and an enquiry as to where the lifted air is dumped and what is the relation between dumping and anticyclones. Some day the study will form an interesting chapter in the life-history of upper air currents.

CHAPTER XIII

SEA FOGS

For those whose business is on the sea, and particularly near coasts or on frequented trade routes, the most important meteorological element is fog. In recent years, since the use of steam power and large vessels has become general, fog is an even more serious obstacle to navigation than strong winds: but it is much less amenable to rules for forecasting. Fog on land is specially characteristic of anticyclonic conditions, which allow a slow drift of air from the warmer uplands over the projections from the moist surface of land areas cooled by radiation, and therefore chill the lowest layer of air. We may summarise the conditions as chilled air, moist ground and a slow drift, either downward along the slopes or across the surface. Land fogs often reach from the coasts over the sea, and, when conditions are favourable for the general development of land fog over our islands and the adjacent parts of the continent, we may find the fog extended over the narrower straits or enclosed seas by a sort of drainage from the land. These are, in the main, the autumn and winter fogs over the seas near our coasts, but the process is not properly characteristic of the formation of true sea fog. Fogs at sea are more generally to be associated with the gradual passage of warm and moist air over cold sea water.

They are most frequent in those parts of the ocean where cold water passes under a warm air-current. It gradually reduces the temperature and increases the relative humidity of the surface layer, while the motion of the surface of air and sea produces the gradual mixing of air of different temperatures which, as we have seen in Chapter VIII., causes condensation in a surface layer. In the localities where sea fog is

prevalent it is most observed in the spring and early summer, when the temperature of the water lags behind the air in the march of the seasonal variation. It is absent or least conspicuous in the winter, when the temperature of the air is apt to be lower than that of the sea.[1]

FOGS ON THE BRITISH COASTS

Hence we may fairly say that sea fogs are summer fogs, and land fogs winter fogs. Coastal regions come in for a share of both kinds; but as regards our own islands the prevalence of fog inland or on our eastern coasts, enclosed seas, or narrow straits, is greater in the winter months, while on the exposed western coasts the early summer is the more notable season of fogs. Particulars of the incidence of fog are given in the table on p. 380 and in the charts of fog at British stations (Fig. 157).

EDDY MOTION

The mechanical process of cooling the air above a cold surface and the consequent formation of fog, if the cooling is pursued far enough, has been explained quantitatively on a physical basis by G. I. Taylor.[2]

The mixing is attributed to the irregular eddy motion which is set up by the frictional effect of the surface, and its irregularities if there are any, upon the air which passes over it. By that effect the moving air is put into a state of motion which is technically known as turbulent. It may be described as the conversion of what might have been a steady flow of air, in which the particles all move in streams parallel to the surface, into a confused turmoil in which a part of the energy of the smooth flow is represented by

[1] See the charts of distribution of fog over the Atlantic Ocean and off the coasts of the British Isles issued by the Meteorological Office (Monthly Meteorological Charts of the Atlantic and Mediterranean, 1909—1910). The observations of fog in the South Atlantic have recently been discussed in the Marine Division of the Meteorological Office and monthly frequencies have been obtained. It is noticed that a very large majority of the fog-observations occur with northerly winds and with air warmer than the sea, and the suggestion of warm air over cold water as a general cause of sea-fogs is confirmed.

[2] "Roy. Soc. Transactions," A, vol. 215, 1914; "Report of the *Scotia* Expedition," Board of Trade, 1913; "Q. J. Roy. Met. Soc.," vol. 43, p. 241, 1917.

AVERAGE NUMBER OF OBSERVATIONS OF FOG PREVAILING AT FIXED HOURS AT VARIOUS STATIONS IN THE UNITED KINGDOM.

Number of Years of Observations at			Station.	The Summer Half-Year. (Days.)				The Winter Half-Year. (Days.)			
8 h. or 7 h. and 18 h.	13 h. or 14 h.	21 h.		7 h.	13 h.	18 h.	21 h.	7 h.	13 h.	18 h.	21 h.
			North Coast.								
20	20	7	Sumburgh Head	10	4	6	9	2	1	1	1
20	20	7	Stornoway	2	0	1	0	1	0	0	0
8	8	7	Castlebay	9	3	7	3	2	1	2	0
20	5	5	Wick	11	8	7	6	1	1	1	2
20	20	—	Nairn	3	2	2	—	2	2	2	—
20	20	—	Aberdeen	4	1	3	—	1	0	0	—
20	—	—	Leith	2	—	0	—	7	—	2	—
			East Coast.								
20	20	2	North Shields	8	2	3	4	8	4	4	6
20	20	7	Spurn Head	7	3	3	4	12	5	7	6
20	20	7	Great Yarmouth	5	1	1	1	25	10	9	8
12	7	7	Clacton-on-Sea	1	0	0	0	6	2	2	1
			West Coast.								
20	20	7	Malin Head	8	4	6	1	3	1	3	1
20	20	7	Belmullet / Blacksod Point	3	1	2	4	2	1	2	2
20	20	2	Valencia	2	0	1	0	2	0	0	0
20	20	—	Roche's Point	8	3	4	—	5	2	3	—
20	13	7	Donaghadee	7	2	2	3	3	2	2	4
20	—	—	Liverpool (Bidston Observatory)	1	—	0	—	6	—	1	—
20	20	7	Holyhead	16	9	9	8	9	4	7	4
20	17	7	Pembroke (St. Ann's Head)	11	6	6	7	7	3	5	5
			South Coast.								
20	20	8	Scilly (St. Mary's)	14	7	9	10	6	4	6	5
20	20	7	Jersey (St. Aubin's)	5	1	3	2	5	2	4	1
20	20	7	Hurst Castle / Portland Bill	5	4	4	3	5	2	2	2
20	20	—	Dungeness	7	2	2	—	10	3	3	—
8	—	—	Dover	3	—	0	—	7	—	2	—
			Inland.								
20	20	5	London	3	0	0	1	19	7	6	8
17	—	—	Oxford	4	—	0	—	24	—	4	—
20	13	7	Loughborough / Nottingham	5	0	0	0	20	6	6	5
12	—	—	Bath	1	—	0	—	5	—	2	—
20	4	—	Birr Castle	4	0	0	—	6	2	1	—

RESULTS FOR THE SUMMER HALF-YEAR
APRIL–SEPTEMBER.

RESULTS FOR THE WINTER HALF-YEAR
OCTOBER–MARCH.

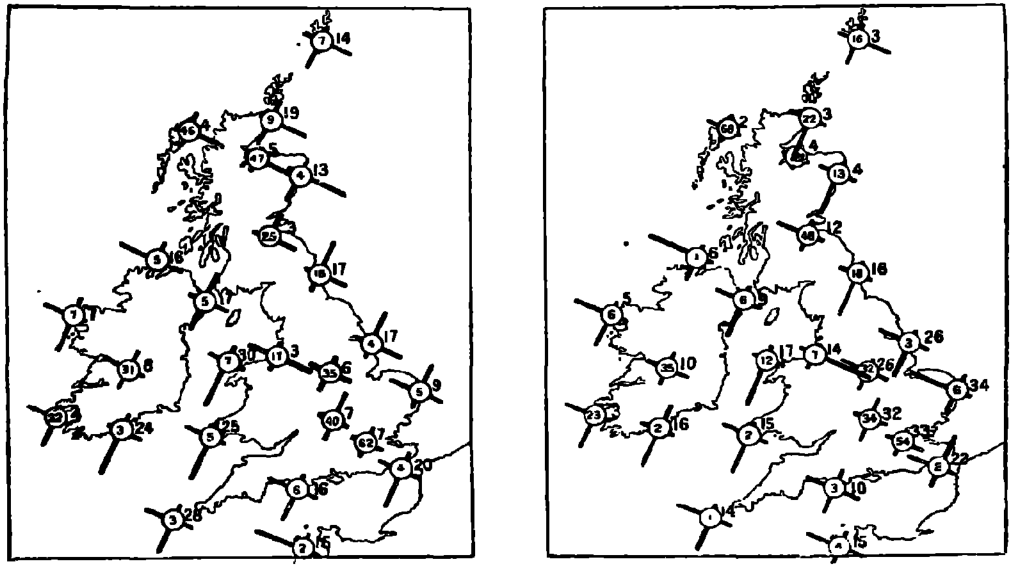


Fig. 157.—Fog at British Stations in Summer and Winter in the Twenty Years 1896—1915.

Explanation of Maps.—The larger figures on the right of the positions of the various stations indicate the number of days upon which fog was reported, irrespective of the time of occurrence.

Wind-roses indicate, for the centre of each of the quadrants, NNW to NE, ENE to SE, SSE to SW, and WSW to NW, the percentage of winds from various quarters reported during the prevalence of fog at the fixed hour of observation, 7 a.m., 1 p.m., 6 p.m., and 9 p.m. The percentage is shown by the varying length of the black lines. The figures within the small circles indicate the percentage of cases in which fog was accompanied by "no wind."

irregular and incomplete eddies constantly forming, changing and decaying in consequence of the relative motion of the contiguous layers but constantly renewed by the frictional effect of the surface.

We may form some idea of what such eddies are like by observing some of the more complete and durable examples, which can be found on suitable occasions. The easiest example to study is what has come to be known as a cliff eddy, which can be observed whenever a strong wind blows upon the face of a nearly vertical cliff. Sea cliffs afford the best examples. It will easily be noticed that at the edge of the cliff one is "out of the wind," because the strong air current passes upwards overhead. What wind is felt there is a light breeze towards the sea forming the lower current of the eddy. An empty match box and even a hat thrown out seaward from the cliff will be carried overhead, and may come back again to its owner along the ground behind him. The interior of the eddy does not consist always of the same wind—the general commotion prevents that—but an inner rotation can be traced in all its parts. At the Meteorological Office are a number of photographs of a small pilot balloon carried round between the top of a cliff and the surface of the sea in an eddy formed below the level of the cliff by the passage of a strong current of air from the land seaward. Corresponding eddies are often seen in water when a strong stream has dead water on its sides.

Such eddies in wind are sometimes very remarkable. I recollect an occasion when there was a gale from the west at Dover and it was scarcely possible to walk on the shore or in the streets on account of the wind. The only place where there was no wind was on the parapet of the Admiralty pier, apparently exposed to the full force of the gale, but really protected from the wind by the deflection of the current upward overhead by the face of the pier. The most notable instance of a cliff eddy on a large scale is that caused by a "levanter," a strong wind from the east, at Gibraltar, which blows on the steep eastern face of the rock. Its effect upon a tube anemometer exposed at the signal station on

the top of the rock is practically to put it out of action [1] because it is adapted only to measure the horizontal wind, and on the top of the rock the wind is deflected so as often to be vertical.

We may think of the eddies formed by any sort of obstacle in the path of ordinary winds, or by the surfaces of the ground or the sea, as things of the same kind, but on a much smaller scale. The eddies at street corners give us a better idea of the process. We see them formed rapidly, persistent for a few seconds, and then destroyed. The best idea of what is meant by eddy motion in the sense in which we are now using it is perhaps to be got by watching the wreaths and whirls of drifting snow formed by the wind passing over the smooth surface of a paved street when there is hard frost and light snow that shows the irregularities of the motion of the air over the ground, or by watching from a cliff the effect of wind passing over the surface of the sea.

Less obviously, but more effectively, the results of eddies can be seen in the trace of a tube anemometer. The pen is constantly moving up and down and draws a broad ribbon instead of a smooth curve in consequence of the eddy motion. The width of the ribbon indicates the gustiness of the wind or the activity of the eddies, and it is easily noted that for the same anemometer and for wind in the same direction the width of the ribbon is proportional to the velocity of the wind.

That is not by any means the only example; for the effects of eddy motion are uncommonly ubiquitous. A factory chimney is almost pardonable when it emits black smoke, because it gives a very effective picture of the result of the eddies which pass over it and disperse the smoke up and down and from side to side as it leaves the chimney and thereafter until it is lost. These effects have recently been carefully studied and we find that the spread of the chimney smoke is a good index of the state of the atmosphere as regards eddies. It follows a law of dispersion which has very general application and ranges from the long streamer of

[1] "Report on Wind Structure," Shaw (Advisory Committee for Aeronautics, R. & M., No. 9); "Eddy Wind of Gibraltar," H. Harries ("Q. J. Roy. Met. Soc.," vol. 40, 1914).

smoke on a nearly calm day, to the spread of the dust-storm of a simoon, perhaps the most appalling example of the result of eddy motion.

It is the atmosphere that provides the eddies, not the object which emits the smoke. Mr. A. Mallock has pointed out that on a calm day when the atmosphere makes no eddies the smoke of a steamer passing through it leaves a long straight trail that takes

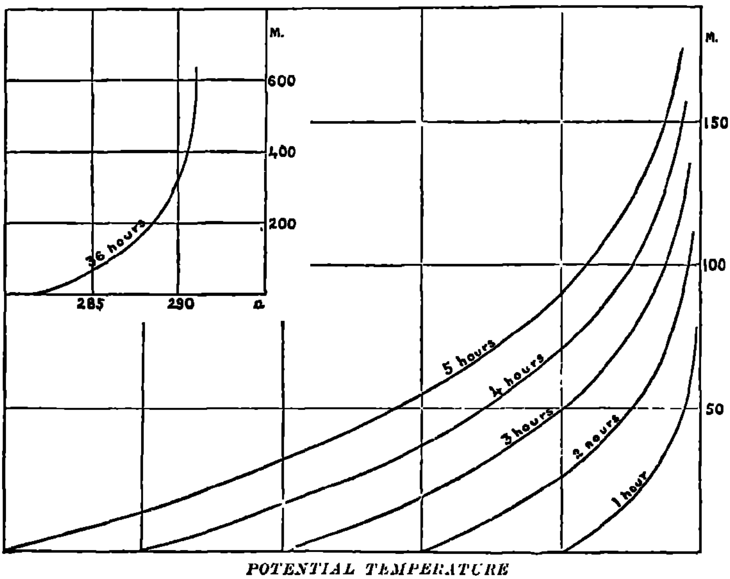


FIG. 158.—Cooling of Air by Mixing. Potential temperature at various heights for a given rate of fall of temperature at the surface.

a long time to disperse. But when there is wind the smoke spreads out and disperses according to the law to which we have referred.

G. I. Taylor has made a great advance in this part of the subject by bringing the phenomena of eddies under numerical calculation. He makes no attempt to trace the course of the air in individual eddies, but shows that their general effect follows the laws which physicists have obtained for the conduction of heat, and the diffusion of gases and liquids. In those processes it is the effect

of the molecules of the gases and liquids which is generalised and, in a sense, the eddies may be regarded as molecules on the large scale, the effect of which can be generalised in like manner. The constant that enters into the equation is such as to give a diffusion by eddy motion much more rapid than by the molecular processes.

In the generalised manner here described, when it passes over cold sea, air is filled with eddy motion which spreads upwards according to the law of conduction: and, as the eddy motion carries with it the cold air from the surface, the air above gradually loses heat and in such a way that the law of conduction may be taken as applying to the "potential" temperature of the air above the cold water or cold ground. The potential temperature is not the same as ordinary temperature. Allowance is made for the automatic rise of temperature that would result from bringing the air downward and increasing its pressure thereby (see p. 60).

The distribution of potential temperature in consequence of the mixture of the air by eddy motion can be represented by the curves of Fig. 158.

The diagram shows the effect on air, originally in adiabatic equilibrium, when the surface is cooled, either by passing over cold water or in some other manner, so that its temperature falls at a constant rate.

The potential temperature of the air initially would be represented by a vertical line on the right-hand side of the diagram, and the distribution of potential temperature after one, two, three, four and five hours of cooling at the surface is shown by the curves. The distance between successive vertical lines of the diagram represents the fall of temperature at the surface in one hour.

The inset shows the theoretical distribution of potential temperature after thirty six hours' cooling under the conditions set out in Fig. 159 which represents an interesting example taken from Taylor's narrative in the Report of the Board of Trade on the voyage of S.S. *Scotia* in 1913.

The distribution which is represented in this diagram is a fair representation of what is found in, and immediately above, a

sea fog. The temperature increases with height until the top of the region affected by the eddies is reached: from there upward the temperature falls in accordance with the usual experience. This procedure is illustrated by an example represented in Fig. 159.

By tracing back the path of the air Taylor found that from "July 28 to 29 the air blew off the mainland and was cooled by the cold water near the coast. It then began to blow on to warmer water and the water-temperature along its path continued to increase till midnight, August 2, or 8 a.m., August 3, when the air began to blow off the warm water towards the cold again."

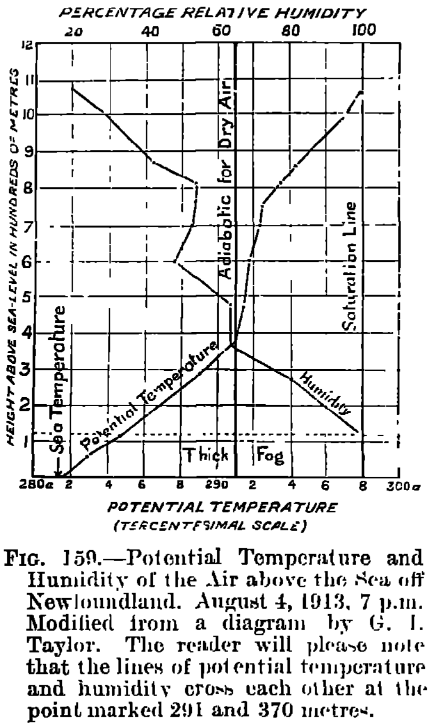


FIG. 159.—Potential Temperature and Humidity of the Air above the Sea off Newfoundland. August 4, 1913, 7 p.m. Modified from a diagram by G. I. Taylor. The reader will please note that the lines of potential temperature and humidity cross each other at the point marked 291 and 370 metres.

All these variations of temperature at the surface may be traced in the distribution of potential temperature in the upper air. The cooling of the surface in the thirty-six hours immediately preceding the ascent has extended up to 370 m. as is shown by the increase of potential temperature up to that height, the effect of the surface-warming from July 30 to August 3 is represented by the approximation towards adiabatic conditions of the slope of that part of the curve between 370 m. and 770 m. and the previous cooling by the greater deviation from the adiabatic state between 770 m. and 1,050 m.

The point to be noticed about the humidity curve is that in

both parts of the curve where the potential temperature is increasing rapidly with height the upper air shows increasing dryness Between those two parts of the curve there is irregularity. The increased humidity of the lower layers is to be attributed partly to evaporation from the surface and partly to the loss of temperature by eddy diffusion.

The question arises as to how far up the process of mixing can be carried. Experienced captains who have navigated in the North Atlantic refer to overlooking a fog from the mast-head, and to looking under a fog by being lowered practically to the level of the sea. On the voyage of the *Scotia* Taylor found the effect of the surface to extend up to heights between 100 m. and 1,150 m. depending presumably upon the time during which the operation had been going on. In the case of land we have not generally the same stretches of surface of continuously falling temperature. Fog in London or its neighbourhood and corresponding localities may, however, extend to a height of 300 to 500 or even 1,000 feet. And there are cases in which the analogy of the long fetch over the sea is reproduced in the formation of fog over, for example, the greater part of Western Europe. We may give January 31, 1918, as a map representing the case in point (Fig. 160).

We see there a very wide current of south wind fed partly by the turning northward of a westerly current from the warm Atlantic and for the remainder by an easterly current coming from the cold Continent and bringing freezing weather in its course. The cold easterly wind chills the whole surface of the ground and as it recedes its place is taken by air having the same direction, but warm and moist on account of its previous history. Then we get all over Western Europe the same conditions which hold off the banks of Newfoundland, namely, warm air passing over a cold surface and, in consequence, a vast area of fog out of which only the higher parts of the land project. On the morning of October 12, 1912. fog was recorded at eleven stations on the English side of the Channel and at other eleven on the continental side.

A very interesting example is to be seen in the maps for

1918. January 31. 7 h.

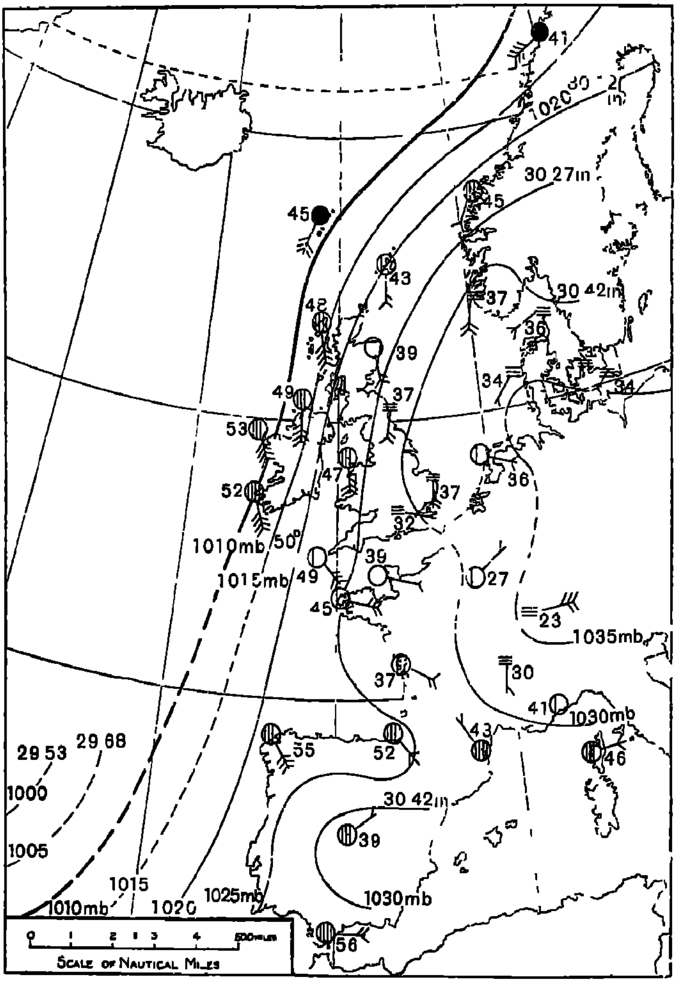


FIG. 160.—Flow of Air along a Line from Madeira to Spitzbergen, causing Fog over Western Europe, probably by the Drift of Warm Air over previously Cooled Ground.

November 10. 1921. when a fog began at 9 a.m. in a southerly wind which had encroached from the Atlantic over the cold ground. It was speedily chased away by an invasion from the east, and the fog vanished when the cold air came back.

We have, therefore, arrived at the conclusion that as a rule sea fogs are due to the cooling of the air by a cold surface over which it passes. The effect is subject to a law of eddy diffusion which is analogous to the process of molecular diffusion but which causes much more rapid interchange of temperature between the surface and the air above it than molecular diffusion would produce. The result of the process is a lower layer in which temperature increases with height. In the colder layers near the surface, fog is formed by the condensation of the water vapour by mixing, but above the fog is a layer in which the temperature is still increasing with height: or in other words, cooling by the influence of the surface has already begun but has not gone far enough to cause condensation.

It is to be noted therefore that the fog is to be found in air which has a considerable range of temperature and since the air may be assumed to be saturated in a visible cloud the amount of *water vapour* in the air as distinguished from the water drops of the cloud is greater above the surface, a reversal of the normal condition.

AMOUNT OF WATER IN FOG-LADEN AIR

From observations on the Austrian Alps it has been ascertained that a visible cloud represents water to the extent of 0·35 g/m³ to 4·8 g/m³. The water suspended as mist, fog or cloud may be taken as between 0·1 to 5 g/m³. The density of water vapour contained in saturated atmosphere varies from 25·8 g/m³ at 300 t. to 4·8 g/m³ at the freezing point and 0·1 at 232 t. Hence above the freezing point the amount of water which is invisible is always greater than that which is visible as cloud.

CHAPTER XIV

WARM WATER FOGS AND THUNDERSTORMS

ALTHOUGH we may regard the gradual passage of moist air over relatively cold sea as the more normal condition for the formation of fog at sea, it is not possible to leave out of account the occasions where fog is apparently formed by the passage of cold air over warmer sea water. We cannot formulate the physical conditions in this case so easily as we can in the case of warm air over cold sea water. There is no difficulty in the formation of the surface cloud by mixing; but we should naturally suppose that, whereas the cooling of the surface layer in the case of warm air over cold sea keeps the air which has been affected close to the surface and in time makes a saturated or cloudy layer of limited height, the warming of the lower layer of a cold current of air would result in the air affected rising out of reach of further warming. We should expect the cloud to be formed, if at all, at some distance above the surface, when dynamical cooling due to elevation had reduced the air below the point of saturation.

In the absence of any quantitative observations which would enable us to examine the separate cases numerically, we can only conclude that the explanation of surface fog by cold air over warmer water lies in the existence of a small lapse-rate of temperature in the surface air-current. If there is little drop

in temperature in the air-current as we go upward, so that we have nearly isothermal conditions, then the warmed air would not rise far before it had become dynamically cooled to the temperature of its surroundings, and the effect of the warming would be limited to a comparatively thin layer. The whole of the layer in question would gradually become saturated, and might pass beyond that point to condensation. Whether this be the full explanation or not, it is a matter of common experience in forecasting that any notable change in the air current is apt to produce fog over the coastal regions. If, after a spell of warm weather, the air supply becomes cold, fog is generally experienced at some point or other of the coast. In reply to inquiry Admiral Sir Reginald Bacon has informed me that the formation of wreaths of mist over the Channel when cold air was passing over the warm water was noticed by the Dover Patrol; and, still more frequently, the replacement of a cold current of air by a warm one after a spell of cold weather shows itself as coastal fog. Hence the note of "fog locally on the coasts" is a frequent addendum to the statement of prospects of weather when a general change of conditions, either from warm to cold or from cold to warm, is expected.

It may, however, be interesting to speculate upon the alternative, or possibly the sequel, to the formation of fog when cold air is to be found over warm water. We have said that the natural process would be for the warmed air to rise from the surface out of reach of further warming, and possibly give rise to a cloud layer not at the surface, but at some distance above it. A fringe of cumulus clouds along a coast-line is often a very noticeable phenomenon. It may be observed frequently with a westerly wind in the English Channel. The clouds may be due partly to the cause which is here indicated, and partly to the mechanical elevation of the air travelling over the cliffs. Sometimes they become sufficiently developed to give rise to smart showers of rain or hail, and sometimes to thunderstorms. It is of interest to note that just as we may draw a distinction between land fog

and sea fog, so we may draw a distinction between land thunderstorms and sea thunderstorms. On our Atlantic coasts we get thunderstorms most frequently in the winter, when fogs are least frequent. and, over land, thunderstorms are most frequent in summer, again, when fogs are least frequent. The coastal thunderstorm is generally incidental to the passage of the trough of a cyclonic depression, the transition from the warm southerly wind to the cold westerly or north-westerly current. The land thunderstorm is similarly most frequently accompanied by the sweeping away of a warm current, or of stagnant air, by a cold deluge from some westerly or north-westerly point.

Hence, to a certain extent fogs and thunderstorms may be regarded as inverse phenomena, and for a good physical reason. The surface fog is characteristic of conditions of stability in the stratification of the atmosphere; the thunderstorm, on the contrary, of marked instability.

What precisely are the causes of the atmospheric instability which give rise to thunderstorms we are unable to say. We cannot regard them as being necessarily of similar character on all occasions. We can imagine, in the case of cold air over warm water, that in consequence of the adjustment of the lapse-rate of temperature, the first effect of the warming of the surface layer may be to produce mixing and fog within a limited height, and that the process may go on until a level is reached, beyond which the lapse-rate of temperature is greater than for the surface layer. When that state of things arises instability may be produced, and the surface layer may find its way upward with great rapidity. The phenomena of the trough of a depression and of the line squall, which are often accompanied by thunderstorms, have been set out in Chapter XI.

We will here only remark that we must be prepared to find a place for thunderstorms of different characters, so far as anything else is concerned than the instability which may be regarded as essential. The thunderstorms which are associated with the trough of a depression, or with well-

marked line squalls, generally commence with a sudden rise

FIG. 161A. 1900. July 27, 8 a.m.

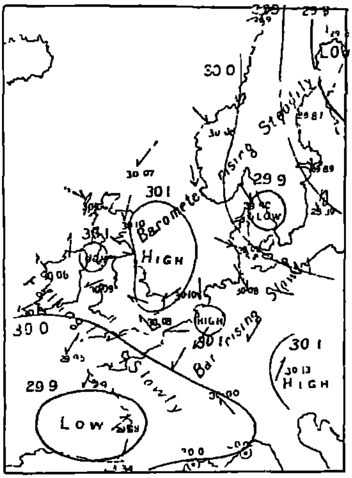
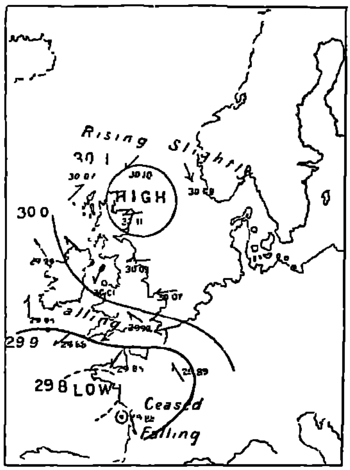


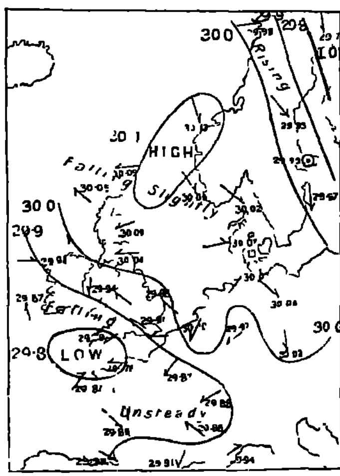
FIG. 161B. 1900. July 27, 2 p.m.



of the barometer, the "crochet d'orage"; but there are many thunderstorms which produce no "crochet" on the barogram; the pressure fluctuations are sometimes hardly noticeable.

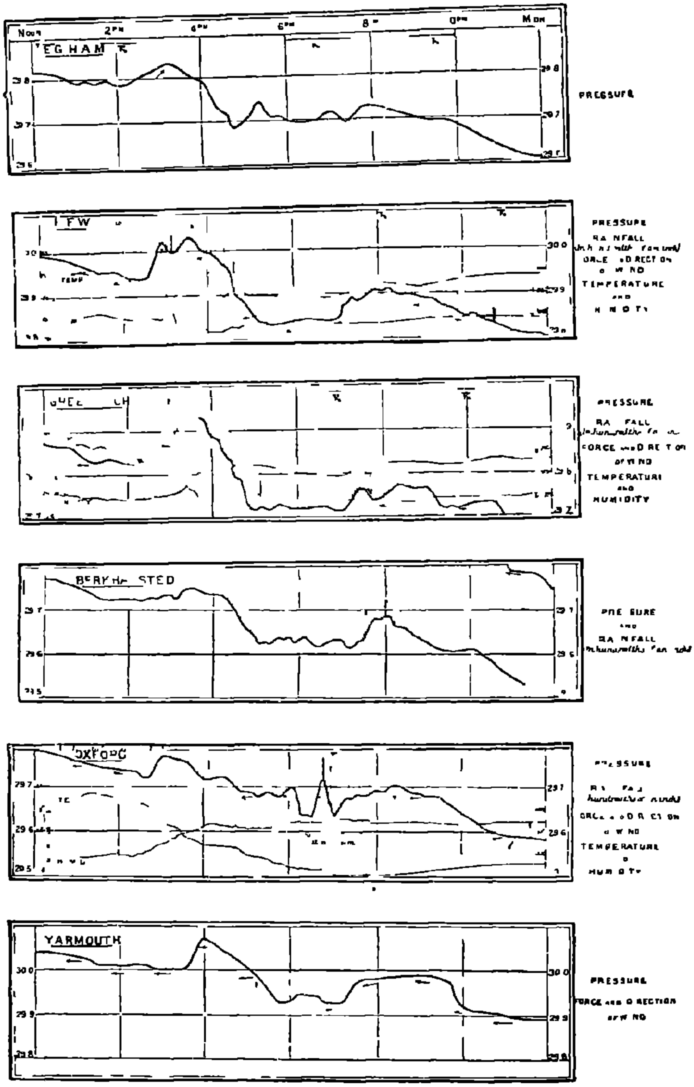
The conditions under which thunderstorms should be forecasted are as various as the types of thunderstorms themselves. The summer storms of land areas are sometimes formed in the debatable region between two cyclones and two anticyclones where shallow depressions are formed, a region which, on the other hand, we have identified in certain circumstances as one of descending air and consequently of

FIG. 161C. 1900. July 27, 6 p.m.



Weather Charts for 8 a.m., 2 p.m. and 6 p.m. of a Day of Thunderstorms.

Records of the Thunderstorm of July 27, 1900.



EXPLANATION OF DIAGRAM

PRESSURE Shown by the thick line. The readings are uncorrected for height and except at Kew Greenwich and Oxford in [illegible] are taken from [illegible] without special means of checking the time scale

TEMPERATURE and PERCENTAGE HUMIDITY are shown by fine lines

RAINFALL For each quarter of an hour short vertical lines are drawn to the barometer curve one for every hundredth of an inch that fell in that interval. Rainfall is only given for stations which have a self recording raingauge. The rainfall at the other stations was either not measured or only the measurements for [illegible] hours are available. The duration of the thunderstorm or thunderstorms is shown by the horizontal lines at the top of the several diagrams

WIND The direction is shown by arrows flying with the wind. The lengths of arrows show the velocity on the scale of 100 miles per hour (nominal) to one [illegible].

Fig. 162

brilliant weather. We sometimes get violent thunderstorms from shallow depressions coming up from the Bay of Biscay, of which a good example, that of July 27, 1900, is given in the Report of the Meteorological Council for 1901 (see Figs. 161A—C). In the east of England there were three thunderstorms on this occasion, as indicated in the diagrams of Fig. 162 by marks at 3 p.m., 8 p.m., and 11 p.m. The first was introduced by a well-marked "crochet d'orage," the second by a less noteworthy barometric change, the third by hardly any change at all. In the summer, thunderstorms are frequently the accompaniments of small secondary depressions, mere deviations of the isobars, belonging to an area of general low pressure, and, as already stated, they sometimes occur as phenomena incidental to the passage of the trough of a depression or a line squall. Hence, in the summer "thunder locally" is almost as frequent an accompaniment of changeable weather as "fog on the coasts."

In this connection let me remark upon the peculiarity which the weather seems to display of taking on "moods," or "fits" as Sir Isaac Newton might have called them, for special types of occurrence. If a thunderstorm occurs on one day in any part of the country, it is quite common for other parts of the country to be visited by similar phenomena on the next day or the day after, although the meteorological conditions do not necessarily point specially to the occurrence. As I write (April 16, 1910), a thunderstorm is passing and storms have occurred at various places in the country during the past three days without any special indication of their likelihood. Why the conditions of instability should be set up in one locality because there was instability in another locality yesterday or the day before, it is difficult to see, but no forecaster can fail to draw the conclusion from experience. It is peculiarly true of thunderstorms and showers that they are conspicuously local, yet at the end of a spell few places seem to have been exempt. Moreover, the same habit is almost equally characteristic of rainfall. After a dry period, the

weather sometimes seems unable to rain even under barometric conditions which are apparently most favourable for it, and on the other hand, rain sometimes falls without any recognisable meteorological reason, even, as we have seen, in the central region of an anticyclone. The peculiar "mood" or "fit" of the weather is a great difficulty for the forecaster. Doubtless an explanation will be forthcoming in due course.

Some light is thrown upon the subject by a paper by E. V. Newnham [1] on the persistence of wet and dry weather in which he shows, from an examination of the records of Kew Observatory, Valencia Observatory and Aberdeen, that the probability of a rain-day "to-morrow" at Kew is 4 to 1 against when there have been eight days without rain, and the probability gradually increases with diminishing spells of fine weather until it is even with one day fine and increases up to only 3 to 7 against when there have been nine rain days in succession. Similar results, with slightly different figures, hold for Valencia and Aberdeen.

Furthermore, with the modern observations of the upper air we may take into account the effects of a spell of dry or of rainy weather upon the upper air in which rain is usually formed. With continued wet weather there is much convection and consequent turbulence, the upper air becomes relatively moist, and at the same time more thoroughly mixed : as an environment it becomes favourable for the convection of any sample of warmer and moister air, whereas, after dry weather, the upper air becomes warm and dry and possibly also relatively stable. Observations of humidity in the upper air enable a distinction to be drawn between these differing characteristics and become an aid to forecasting during spells of fine or wet weather.

It will be noticed that I have given no physical theory of the development of electricity in a thunderstorm. I have not done so because I know of no explanation that can be regarded as applicable to the different types of storm. If I had been able to supply an adequate theory it would probably have explained why, when Nature was in the mood, every rain-shower was a thunderstorm, whereas on some other occasion

[1] "Q. J. Roy. Met. Soc.," vol. 42, p. 153, 1916.

the longest period of hot weather passed quietly away without a single peal of thunder.[1]

NOTABLE THUNDERSTORMS SINCE 1910

We may add some notes on the notable thunderstorms which have occurred since the preceding paragraphs were written, and which have been the subject of special investigations. Mr. J. Fairgrieve has given some very full details,[2] including some half-hourly maps of rainfall of a remarkable storm in the south of England on the afternoon of May 31, 1911. The storm is memorable because it caught the crowds on Epsom racecourse, as the day was Derby day, and impounded the members of the Gassiot Committee of the Royal Society (a recent creation in connection with the management of observatories) at the conclusion of its first meeting at Kew Observatory, Richmond, by submerging the District Railway at Gunnersbury and otherwise stopping traffic. Subsequently,[3] the same author has discussed in like manner the details of the distribution of cloud and rainfall in a notable thunderstorm which occurred in the neighbourhood of London and the south of England on June 14, 1914.

In No. 8 of the "Professional Notes of the Meteorological Office," [1] Captain C. K. M. Douglas, R.A.F., discusses the observations of temperature and humidity in the upper air obtained in France and "the conditions favourable for thunderstorm-development." He groups thunderstorms into three classes :—

(a) Those due mainly to heated surface air in fine sunny weather.

(b) Those associated with powerful upper currents from SW. the surface wind being light and variable or south-easterly.

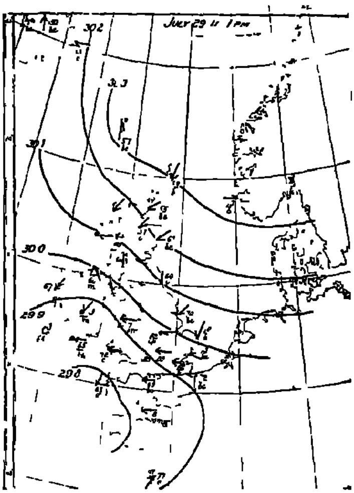
[1] The reader who wishes to examine recent theories of the origin of the electricity of thunderstorms may consult the following: Dr. G. C. Simpson, "Phil. Trans. A.," vol. 209, p. 379; "Phil. Mag." (6), vol. 17, p. 619, 1909; C. T. R. Wilson, "Proc. Camb. Phil. Soc.," vol. 13, p. 363, 1906; London, "Phil. Trans. R Soc.," 221, 1920.

[2] "Q. J. Roy. Met. Soc.," vol. 38, p. 105, 1912.

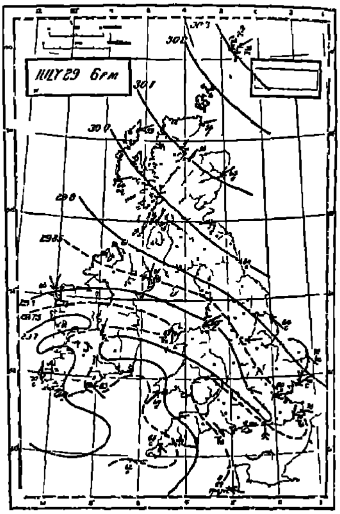
[3] "Q. J. Roy. Met. Soc.," vol. 44, p. 245, 1918.

[4] "Temperatures and Humidities in the Upper Air: Conditions favourable for Thunderstorm Development and Temperatures over Land and Sea" (M.O. Publication, No. 232h. 1920).

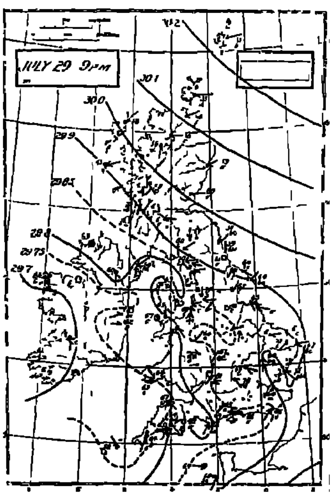
1911. July 29, 13 h.



1911. July 29, 18 h.



1911. July 29, 21 h.



1911. July 30, 7 h.

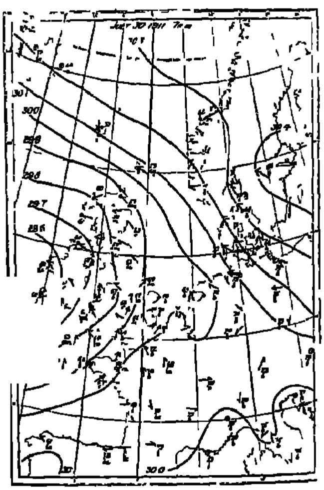


FIG. 163.—Thunderstorms over the British Isles, 1911. Isobars, winds and weather for 13 h., 18 h., and 21 h. of July 29 and 7 h. of July 30.

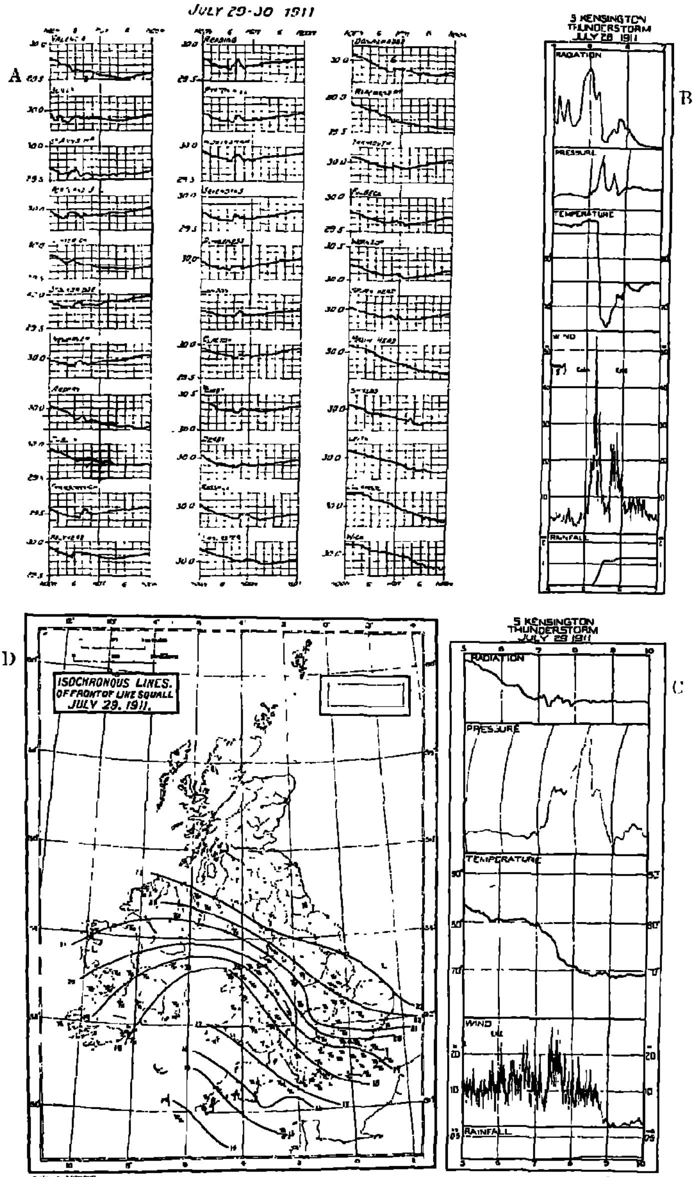


Fig. 164.—A. A Collection of Barograms for July 29–30, 1911. B C. Meteorograms for South Kensington, July 28 and 29. D. Lines of Progression of the Thunder Squall from 14 h. to 23 h., July 29, from SW to NE. The symbol K indicates the locality where a thunderstorm was noted.

(c) Those associated with very low upper air temperatures in the south-westerly or north-westerly currents of cyclonic depressions.

Here, for the present, we confine ourselves to giving illustrations: (1) of a very widespread series of thunderstorms on July 28 and 29, 1911. Maps for 13 h, 18 h, and 21 h of July 29, and 7 h of July 30 are given in Fig. 163. We quote from the "Report of the British Association. Portsmouth Meeting, 1911":—

"On the afternoon of July 28 the western districts of London were visited by a severe thunderstorm and in the afternoon and evening of the following days thunderstorms occurred over nearly the whole of England and Ireland. The London storm (Fig. 161) was accompanied by a squall of wind which reached fifty-four miles per hour at South Kensington, and the storms of July 29 were preceded by a violent squall which raised clouds of dust particularly noticeable in South Wales. There were also marked oscillations of the sea on the south coasts (Fig. 165).

"Meteorograms from records taken at the Meteorological Office at South Kensington are shown in Fig. 161, B and C. That for July 28 was of the ordinary thunderstorm type—a sudden rise of pressure, which gradually fell off, accompanied by a drop of temperature of more than 20° F., a wind squall of fifty-four miles per hour with a change of direction, probably from E to SW, and a rain shower giving an inch of rain in less than twenty minutes. For the following day the sudden rise of the barometer was followed by violent fluctuations; there was little fall of temperature, not much wind, and little rain.

"Barograms and anemograms from all parts of the country show the shape of the *crochets d'orage* and the time of its occurrence at different stations. They show that the disturbance of July 28 was confined to the neighbourhood of London. That of July 29 was very widespread, as the barograms for that day reproduced in Fig. 164, A, show.

"The most characteristic curve was that from Watlington, Oxon. Pyrton Hill, which showed that the *crochet d'orage* occurred

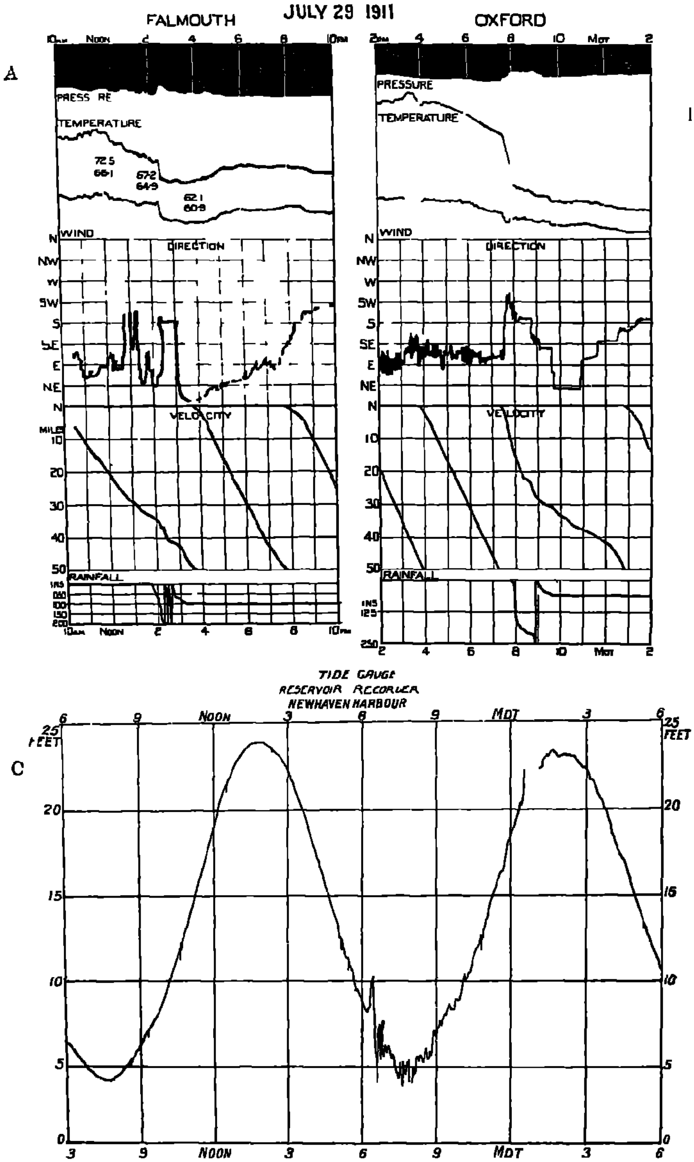


FIG. 165.—Records of the Thunderstorm of July 29, 1911. A. Meteorogram for Falmouth, 10 h. to 22 h., 29th. B. Meteorogram for the Radcliffe Observatory, Oxford, 14 h., 29th, to 2 h., 30th. C. Tide gauge at Newhaven Harbour, 6 h., 29th, to 6 h., 30th.

while the passage of a depression was in progress, apparently just before the minimum was reached. The *crochet* of disturbance gave an M-shaped figure, which it took about two hours to complete. A somewhat similar figure is noticeable at many other stations in the region of the south and west.

"The weather maps showed that the storms of July 29 were incidental to the setting in of a south-westerly current of air, replacing an easterly current which had formed the northern part of a shallow low-pressure to the south-west of Britain. By the following morning, July 30, the new south-westerly current formed the eastern section of a well-developed cyclonic depression with its centre off the west of Ireland.

"The barograms showed that the *crochet* disturbances could be arranged in isochronous lines indicating the advance of the *crochet* and its attendant squall with a linear front, which passed over Scilly at about 2 p.m. on July 29. Over England the front was generally ranged from NW to SE, and it advanced with the SW wind, but the lines were bent apparently over the Irish Sea, and the direction of the front over Ireland was not very well traced. The disturbance advancing with this front was attended nearly everywhere by thunderstorms, but in the north of England its intensity was much diminished and it was barely recognisable in barograms for the north of Scotland on Sunday morning. The anemograms showed that at many stations in the south the wind-squall commenced at the full strength of gale force without any preliminary gusts. The lines of advance of the thunder squall are shown in Fig. 164, D.

"The peculiarity of the disturbance is its M-shape and its line of advance in front of a SW wind. It is thus distinguished from the ordinary type of line squall, which has a V-shaped *crochet*, and comes from the W or NW."

Other illustrations of this remarkable storm are given in the meteorograms for Falmouth and Oxford (Figs. 165, A and B), and in the record of the tide gauge of Newhaven Harbour (Fig. 165, C) which shows remarkable fluctuations caused by the storm.

(2) We give also a map illustrating the tornado which passed

1913. October 27, 6 p.m.

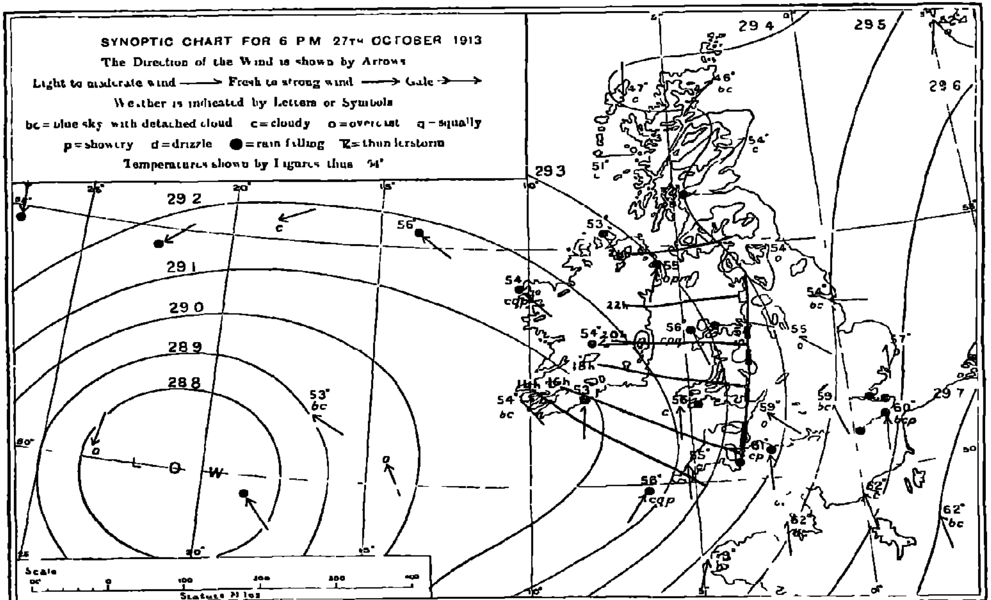


FIG. 166.—Chart illustrating the Occurrence of a Tornado in South Wales. The track of the tornado is shown by a line between the isobars of 29·3 in. and 29·4 in. The thickened parts of the track mark the regions of the more notable disturbances. The lines across the isobars are isochronous lines for the advance of the front of a disturbance between 14 h. and 24 h. which culminated in the tornado at its eastern end in South Wales at 18 h. (See "Geophysical Memoir," No. 11.)

over South Wales on October 27. 1913 (Fig. 166), during which the lightning display was very remarkable. It was said to have set fire to a roadway recently coated with tar.

(3) Also maps of the conditions under which a "cloud-burst" was said to have occurred as the cause of a flood which suddenly overwhelmed the town of Louth during the progress of a thunderstorm in the afternoon of May 29th, 1920 (Fig. 167A and B).

1920. May 29.

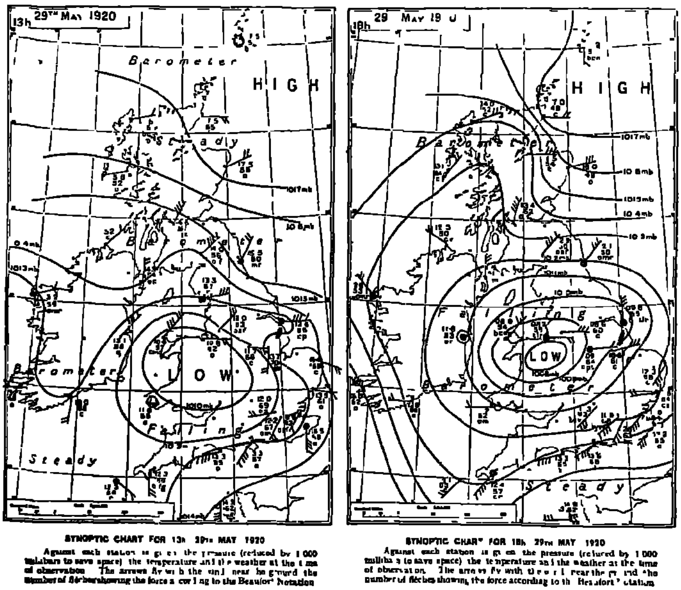


FIG. 167A.—Synoptic Charts illustrating the Louth Flood.

We have drawn a distinction between sea thunderstorms as winter phenomena and land thunderstorms as summer phenomena. We might also amplify the contrast by the remark that land thunderstorms occur most frequently in the afternoon whereas sea thunderstorms are apt to occur at night. We may perhaps develop this idea by premising that the instability which causes the violent thunderstorms which are sometimes experienced over England in the night or early morning is due to exceptionally warm and moist air which has come from the western or south-

western sea and has taken some hours to reach the elevation where the instability began. On occasions we may watch a

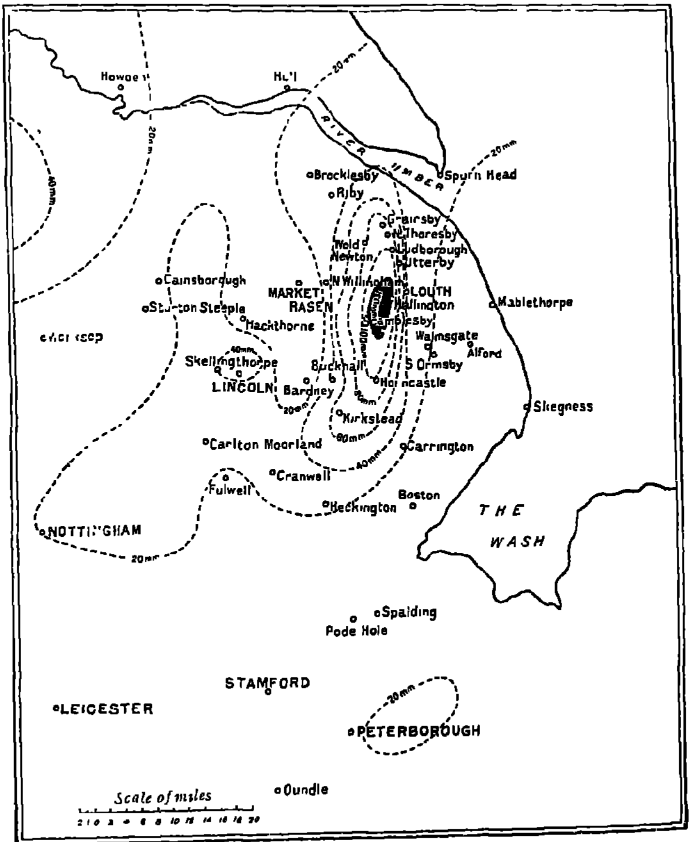


FIG. 167B.—Map showing Rainfall for the Twenty-four Hours ending at 9 h. G.M.T., May 30, 1920. Nearly the whole amount fell between 13 h. and 17 h. on May 29. The dotted lines are isohyets for intervals of 20 mm. In the region on the west of Louth the fall exceeded 120 mm. (Professional Notes, No. 17.)

cumulus cloud drifting from the south or south-west and gradually getting thicker by the development of its head until it becomes a cumulo-nimbus. If we take account of its horizontal motion as well as the vertical movement we may make an estimate of the

time which it must have taken to rise from the surface and the distance from which it started. The slope of the line of resultant cloud motion as thus computed is sometimes so slight as to point to the regions beyond the coast as the locality from which the rising air started. Whatever truth may be in this speculation it may at least lead us to conclude that the air which forms the thunderstorm over our heads is certainly not the air which has started from the ground at our feet.

Note.—April 20, 1923. Thunderstorms in winter have been the subject of a number of recent papers: Mr. E. V. Newnham has discussed their formation in a Professional Note, No. 29, M.O. 245I, and Captain Douglas in the Meteorological Magazine for April, 1923. Captain Cave has treated of their frequency in Q. J. Roy. Met. Soc., vol. 49, p. 48, 1923. These papers throw some additional light on the points raised in this chapter.

CHAPTER XV

THE UPPER AIR FORECASTS FOR AIRCRAFT

In recent years our knowledge of the upper air has been largely extended by investigations with manned balloons, captive balloons, free unmanned balloons or *ballons sondes*, pilot balloons, and kites. To these aeroplanes may now be added.

From manned balloon ascents we can learn something of the actual trajectories of air, provided the balloon has been kept within what we may call the same current. A balloon that simply floats at the same level in a horizontal current drifts along, and its trajectory is that of the air which forms the current, but there are many occasions, as we have already seen, when the currents at different levels are in different directions, and on such occasions the direction in which the balloon drifts must be dependent to some extent upon the level at which it floats. Moreover, the course of the air itself can seldom be truly horizontal, so that if the balloon is kept strictly at the same level it gradually separates from the air which has been bearing it; hence the horizontal projection upon a map of the trajectory of a balloon may be different from the surface trajectory of air, and sometimes considerably so. In order, therefore, properly to co-ordinate the information derived from the track of a balloon as plotted on a map we require to know the heights of the successive steps. The heights can be obtained from the air-pressure as read on a barometer, provided that the temperature of the column of air from the balloon to the ground is also known. This requires accurate readings of temperature, which are difficult measurements for balloonists, because the thermometer is liable to be much affected by the sun's radiation, either directly upon the instrument or indirectly through the effect of the

envelope or car of the balloon. Arrangements have therefore to be made for keeping the thermometer out in the air some five feet away from the car, for reading it with a telescope, and for protecting the bulb by a highly polished metallic envelope, and producing an air current over it sufficient in velocity to obviate any error due to radiation. The apparatus which is in general use for this purpose is the ventilation psychrometer designed by Professor Assmann. As its name implies, it provides for a wet bulb as well as a dry bulb, so that the humidity can be determined at the same time as the air temperature. Strictly speaking, something more is required than the readings of the air temperature in the balloon, because we want to know the temperature of the column between the balloon and the earth, and the temperature at the ground is not generally known, but a reasonable approximation can be made to it in ordinary circumstances.

As a rule manned balloons keep within the limit of 10,000 feet, but they are available for observations up to 20,000 feet, and on exceptional occasions have been up to 30,000 feet. The last-named limit is practically also the limit of the highest clouds, and manned balloons may be especially useful on account of the opportunities which they afford for the study of cloud forms, by photography or otherwise, from a point of view unattainable on *terra firma*. The voluminous publication of the Berlin Aeronautical Society, "Wissenschaftliche Luftfahrten," may be referred to for some interesting examples of photographs and sketches from balloons.

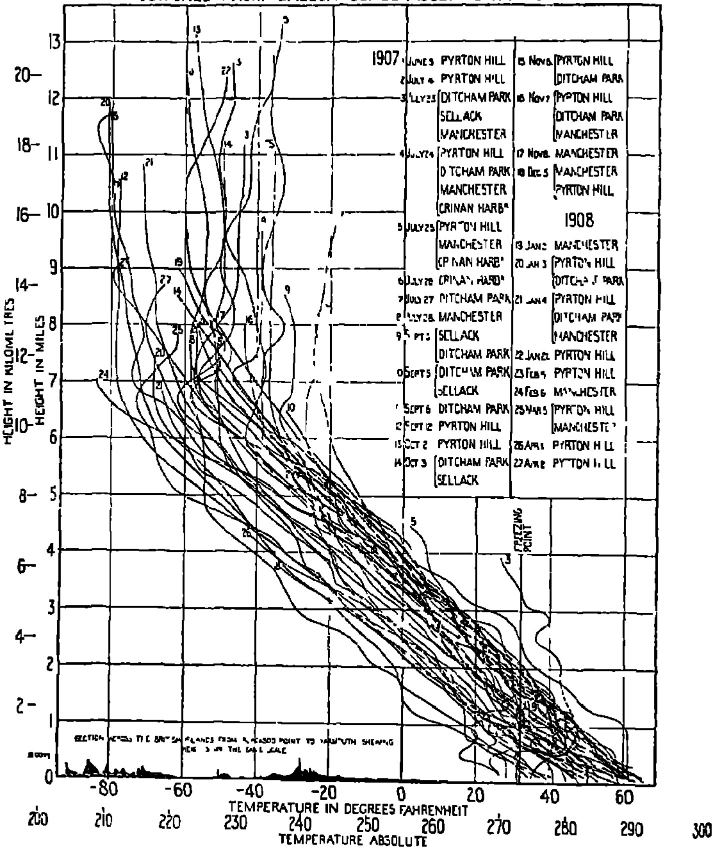
Captive balloons, either of the ordinary form or in that of the balloon kite of the German Aeronautical Service, give results similar to those of manned balloons or kites, but they are restricted to more limited heights.

The free unmanned balloons, or *ballons sondes*, which carry self-recording instruments according to the plan of Hermite and Besançon, have been largely used in recent years for obtaining information about the higher strata of the atmosphere. A record has recently been obtained from the great

height of twenty-three and a half miles, and heights of ten to fifteen miles have frequently been reached. Ascents have been made in many countries on an international basis, and it is hoped that the co-operation of the countries interested in the study of the air will shortly be restored. At great heights water vapour ceases to have much importance as a constituent of the atmosphere (see p. 220), and attention is concentrated mainly upon the records of temperature. It has been clearly established that up to a height of about ten kilometres in these latitudes, a greater height in equatorial regions, and a less height in more northern latitudes, the temperature falls off at a rate which corresponds nearly with that of the adiabatic for saturated air, about ·56° C. for 100 metres, or 1° F. for 300 feet. When the critical height is reached a sudden change in conditions takes place. The temperature either rises again or becomes stationary as regards the trajectory of the individual balloon, but it changes considerably from place to place and from day to day. A very good general idea of the state of affairs in the atmosphere as regards the variation of temperature with height may be obtained by an examination of Fig. 168, which shows the curves of change of temperature with height above sea-level obtained from *ballon sonde* ascents reported to the Meteorological Office in 1907-8.

The results already obtained have enabled us to give the provisional sketch of the temperature of the atmosphere which appears in Fig. 12. We must clearly regard the atmosphere as divided into two portions—the upper, more or less isothermal portion, to which M Teisserenc de Bort has given the name of *stratosphere*, and the lower portion, in which there is a fairly regular fall of temperature with height, and which he has called the *troposphere*. The troposphere is thicker at the equator than at the poles and the temperature of the superincumbent stratosphere is colder there: indeed, the coldest air in our atmosphere is to be found in the stratosphere over the equatorial regions. The name *tropopause* has been coined to indicate the boundary between the troposphere below and the stratosphere above. It

CURVES SHOWING CHANGE OF TEMPERATURE WITH HEIGHT ABOVE SEA-LEVEL.
OBTAINED FROM BALLON-SONDE ASCENTS 1907-8



The separate curves represent the relation between temperature in degrees Fahrenheit or on the tercentesimal scale and height in miles or kilometres in the atmosphere. The numbers marking the separate curves indicate the date of ascent at the various stations as shown in the tabular columns. The general aspect of the curves shows the great complexity of the temperature variations within the first two miles from the surface, and a very nearly uniform rate of fall of temperature above the two-mile limit until the isothermal layer is reached, at from six to eight miles. The difference of height at which the isothermal layer is reached, and the difference of its temperature, for different days or for different localities, are also shown on the diagram by the courses of the lines.

FIG. 168.

is indicated on Fig. 12 by a shaded band highest at the equator and sloping downwards towards either pole.

The stratosphere is, as a rule. beyond the reach of aeronauts, except, perhaps, in the arctic and antarctic regions, so that we need not deal with the results of this investigation further than to suggest that the changes of temperature which have been disclosed in these high altitudes must be associated with changes of pressure. Any such changes of pressure are transmitted to the surface and affect our air currents in ways with which we are at present unacquainted.

Ballons sondes give us very inadequate information about the air currents which they penetrate, unless they are observed from below with theodolites. For the most part they reach the earth again at some place to the east of the starting point, but they carry no record of the details of their journey, and they sometimes retrace in the upper regions the steps which they took in the lower.

Watched by theodolites from minute to minute they afford a most effective means of determining the direction and magnitude of the currents in the upper air, and are on this account of the greatest utility for aeronauts. For this purpose, also, balloons smaller than those required to carry self-recording apparatus may be used. and a very simple equipment of two theodolites, a stock of balloons, and some steel bottles of hydrogen enables aeronauts to make most useful explorations of the state of the air currents overhead. Balloons of this kind have now been introduced into the recognised equipment of a selection of the telegraphic reporting stations at comparatively little expense and with great advantage in forecasting. The smaller balloons without instruments, and generally without theodolite observations, are known technically as *pilot balloons ;* recently their use in meteorological investigation by the introduction of theodolite observations has become much extended.

The last method which we have to mention for exploring the upper air is that of the kite which has been used in many countries to carry self-recording instruments in favourable

weather to a height of 10,000 feet (3,000 metres). With proper equipment, greater heights are attainable, but in view of the restrictions of the conditions, it is doubtful if the higher ascents yield an adequate reward for the additional effort. Kites are only available within a certain restriction of meteorological conditions. There must be wind enough in the surface layers to raise the kite, and not enough in the upper air to carry it away altogether. As the forms of kites are improved the range of availability is widened, and in course of time we may come to arranging for kites to be kept up more or less permanently in the air and for information to be obtained from them at fixed hours by running up a "traveller," as has been done experimentally in connection with the Indian Meteorological Service. In Germany and in the United States kites are used to give daily readings of temperature, humidity and wind velocity in the upper air. In this country daily observations organised by the University of Manchester were made at the Howard Estate Meteorological Observatory at Glossop Moor during the years 1908 and 1909: occasional observations were made for some years at Oxshott or Pyrton Hill, Brighton and Ditcham Park. The observations made in this country have been published week by week in the Weekly Weather Report since the beginning of 1906. The observatory of Professor A. L. Rotch, of Blue Hill, Massachusetts, is justly celebrated for its contributions to the development of the use of the kite in meteorological research.

In consequence of the active investigation of the upper air in many countries by the methods named we are now in possession of a great deal of new information which is gradually being incorporated in meteorological work.[1] I propose to give here in a few sentences the results of the investigation which have lent themselves to effective generalisation.

So far as temperature is concerned there is on the average,

[1] See "The Free Atmosphere of the British Isles" (M.O. Publication, 202, 1909); "Geophysical Memoirs," No. 2 (M.O., 210B, 1912); "The Characteristics of the Free Atmosphere," "Geophysical Memoirs," No. 13 (M.O. 220c, 1919).

as I have already mentioned, a lapse-rate of temperature of about 1° F. for 300 feet up to the limit of the region likely to be reached by aeronauts, but within the first two miles the lapse-rate is very irregular. Indeed, it may vary from something more than the adiabatic lapse-rate for dry air, 1° C. for 100 metres, to zero or a negative quantity. There are quite frequently inversions of lapse-rate or negative lapse-rates—that is to say, after falling with elevation for some distance the temperature rises again; at still greater heights the fall recommences. Negative lapse-rates are often to be found in winter in the surface layer itself in consequence of surface cooling. They also occur frequently when a cloud layer has been traversed, and as there may be several separate cloud layers in the path of a balloon or kite the variations of temperature may be very complicated. They are, indeed, too complicated for general practical rules to be drawn from them. An aeronaut who wishes to take account of the changes of temperature which he will meet must give something more than cursory attention to the results obtained from the upper air investigation, and provisionally must draw his own conclusions. The diagram, Fig. 168, sufficiently illustrates the complexity of this subject in the lowest strata of the atmosphere.

The variations in humidity are even more irregular than those of temperature. The diagrams prepared for "Barometric Gradient and Wind Force" (Fig. 169) illustrate the great diversity in the measurements of humidity obtained by Mr. Dines at Oxshott in the year 1905. The diagrams show, by means of points at ground level, and at 500, 1,000, and 1,500 metres above it, how the humidity varies from its value at 500 metres taken as datum point. An increase of humidity at the higher level is shown by the point for that level being placed to the right of the 500-metre point according to a scale given in the diagram. The variation is greatest with south-westerly winds and least with north-westerly. The numbers on the diagram indicate the number of observations of which the average has been taken.

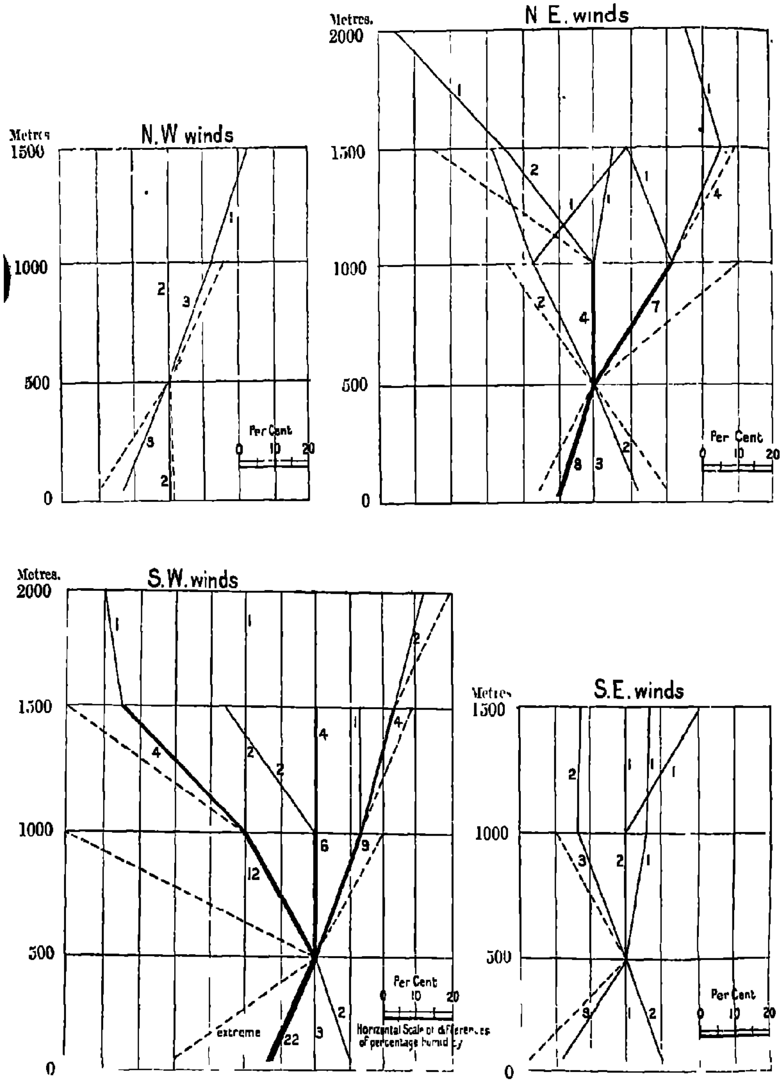


Fig. 169.—Variation of Relative or Percentage Humidity of the Air with Height as determined by Kite Observations at Oxshott.

The diagrams show by how much the humidity at the several stages, ground-level, 1,000 metres, 1,500 metres, and 2,000 metres differs from the humidity at 500 metres. The difference between two vertical lines represents 10 per cent. Dotted lines show extreme limits of variation.

One cannot say that the variations of wind velocity with height are more free from irregularity so far as observations go, but we are able to draw from them some more general conclusions than is possible in the case of the other elements referred to. In the first place, it has been shown that as a general rule the computed gradient wind velocity is more nearly approached both as regards direction and speed at a considerable height above the surface, say at 500 metres, or 1,500 feet, than it is at the height of an ordinary anemometer.

We have already, in Chapter IV., discussed the variation of wind, as regards both direction and velocity, from the surface up to the level where it agrees with the gradient wind. In the higher regions, after the gradient velocity has been reached, all sorts of different conditions have been identified by means of pilot balloons Sometimes the velocity increases considerably beyond the gradient velocity without any change in direction; sometimes it falls off nearly to nothing and the direction becomes reversed. Sometimes the gradient velocity is never actually attained. Here we have to deal with two separate issues; first, the meteorological conditions may be such that the wind velocity, quite apart from the friction of the surface, is not in the steady condition which the gradient velocity truly represents; and secondly, the gradient velocity itself may be different in different levels. The meaning of these exceptional cases is at present a subject of investigation. Some information bearing on it may be found in "Manual of Meteorology, Part IV." (Cambridge University Press, 1919).

FORECASTING FOR AERONAUTS

The application of our knowledge of meteorology for the information of practical aeronauts is to a certain extent a separate branch of the subject. The pilot of a balloon or an airship wants detailed information as to air currents and weather conditions perhaps for only a few hours ahead, which are not of much practical importance for other people, and

which are not included in an ordinary forecast of weather. Supposing that the general inference set out as the basis of the forecasts is correct, it has to be interpreted to meet the special circumstances of the aeronaut. The interpretation requires the combination of the knowledge possessed by an aeronaut and a meteorologist, because the aeronaut alone knows the special conditions which he wishes to make use of or to avoid, and the degree of probability for a meteorologist's anticipations of changes depends upon conditions which ought to be appreciated by the person who takes the risks, but which cannot easily be expressed in words.

Let us take, for example, the case of a south-westerly or westerly current; there is always in such currents the chance of a line-squall within twelve hours which might be fatal to an airship away from its base, but the chance of using telegraphic information to avoid such a mishap depends on the position of the station and the possibility of the squall passing the outlying stations without being identified. Something more than a forecast of local showers, and a general recommendation to "look out for squalls," is wanted before an aeronaut could decide whether or not he ought to take the risk. An aeronaut with a competent knowledge of meteorology and of the sort of information which is included in telegraphic reports, and the hours at which they are ordinarily made, could easily frame questions to which definite answers could be given either by a map before him or in reply to telegraphic inquiry.

Moreover, an aeronaut may wish to know what the variations of the currents in the upper air will be, and whither they would carry a balloon in a free run, or what prospect there is of using adjustment in the vertical to get over difficulties offered by the surface current. These are problems of detail for which a meteorologist can often suggest a solution, but it requires the supplementary assistance of local knowledge more than does the ordinary forecast for local agricultural purposes. It is useless, for example, to look for a return current from

the west over a surface easterly current if the highest clouds seen from the station are drifting to the west.

Further, it is important that the aeronaut who wishes to make use of a forecast should recognise for himself the signs of its progressive fulfilment or its failure. If, for example, it has been anticipated that a depression of some depth will pass over a particular locality, the anticipation may fail in important detail, because the depression takes a different course from what is anticipated, or because it is itself either less deep or it travels slower or faster than the forecaster thought it would. All these variations from the expected are to a certain extent indicated by barometer and wind observations on the spot, and the local information, therefore, may supply the necessary corrections.

With his local knowledge the observer in the locality could make out a time-table for the succession of events, which would be quite serviceable for his own purposes, but he would be ill-advised to publish it *urbi et orbi*, because the reservations that he would make as to certain anticipated conditions being fulfilled would be known to himself, but not to the general reader who would attribute equal authority to every item of his specification.

Hence it would appear that the proper course to be pursued with regard to forecasts of weather for the use of aeronauts is for someone attached to the aeronautical depôt to be placed in charge of the means of making meteorological observations in the locality, which would be constantly brought into comparison with the anticipations of a general inference. He would thus become acquainted with the special modifications incidental to the various types of weather, and be able to fill in the details for the use of himself and his colleagues.

CALCULATION OF THE TRACK OF A FREE RUN

One of the most direct applications of the use of synchronous charts for aeronautical purposes is the calculation of the free run of a balloon. For this purpose the determination of the

gradient wind velocity is the first necessity, and to that we must add an anticipation of the manner in which the barometric distribution is likely to travel and to change. The various kinds of trajectory for a free run under various conditions, supposing that the surface current is used for the transport, are represented by the various trajectories drawn in the "Life History of Surface Air Currents." Calculations of this kind have been used on various occasions for selecting an opportunity for crossing the Channel in a balloon, notably on two occasions of attempted long-distance journeys for the *Daily Graphic*, the first of which landed the aeronauts in Sweden and the second in Russia, and also on the occasions of the late Mr. C. F. Pollock's adventurous journeys to North Germany.

MODERN DEVELOPMENTS

When the preceding paragraphs of this chapter were written the use of aeroplanes and airships had only just begun. The experience upon which it relied was found almost entirely in the application of meteorological information to the requirements of pilots of manned balloons. Within the past twelve years, and especially during the war, the whole situation has been changed. The number of pilots of aeroplanes grew until they were numbered in tens of thousands: airships were in regular use for the patrol of our coasts. The kite-balloon, which has already been referred to, became an established method for sending up observers to a height of some thousands of feet for various purposes, and the design of the balloons themselves and of the gear for manipulating them was developed to a high degree of perfection. Towards the end of the war apparatus was designed for obtaining automatic records from kite-balloons, so that the services of an observer might be dispensed with and a corresponding additional height, perhaps up to 15,000 feet, reached. At the same time additional methods were devised for obtaining the velocity of winds at different levels by observations upon the smoke of shells fired from guns to great elevations and timed to explode at suitable levels. The motion of the smoke could be measured either by tracing its

track on mirrors at the ends of a suitable base line for obtaining satisfactory estimates of the height and distance, or by the observer of an aeroplane flying through a series of puffs representing explosions at fixed intervals and at approximately the same height. Such methods are too expensive in working for a meteorological establishment in peace time, but the use of a kite-balloon to obtain automatic records irrespective of the presence of clouds, which interfere for different reasons with the operations of a pilot balloon and an aeroplane, is sufficiently desirable to justify the expense for a select number of stations designed to supply information for aviation and for gunnery.

In the meantime the policy of employing a trained meteorologist at aerodromes, which was indicated on p. 417, has also been developed. It began before the war, first at South Farnborough, and then at the Central Flying School at Upavon. It was then extended to a number of airship stations at points on the coast and at various centres in the several theatres of war, and has now come to be recognised as an essential part of any organisation for aviation, whether military or civil. Such centres enjoy special facilities and become important stations for meteorological observations in the upper air. The connection between meteorology and aviation has become so close that the Ministry which has become responsible for aviation has taken over also the responsibility for the national meteorological services ; and the Meteorological Office which, on account of its scientific responsibilities from 1867 up to 1919, had been independent of ministerial control and responsible only to Parliament through the Treasury for the expenditure of the public funds assigned for its maintenance, became attached in that year to the Air Ministry through the Department of Civil Aviation. The official aerodromes have now become the chief centres for the daily supply of information for the study of the upper air, and the forecast-service of the Office has for its primary and immediate object the satisfaction of the requirements of aircraft.

The application of meteorology for the purposes of aerial navigation has therefore become the leading line in the practical

applications of meteorology: and the traditional applications to gale or storm warnings for ships, fogs on land or sea, agriculture and colliery warnings, which are set out in five chapters which follow, have taken their place in a much more elaborate system in which the navigation of the air is prominent. We must therefore commence our sketch of the practical applications of the use of the weather map with the presentation of the system adopted for aircraft, instead of, as formerly, beginning with the warnings of coming gales.

The application covers a very large range. We may begin with the forecasting of an aeroplane from London to Paris by four short stages of half an hour each, and lead up to the mapping of the world's air routes, and the selection of the most suitable sites for aerodromes on the routes, or, more likely, to the criticism, from the point of view of weather, of the selection that has been made on other grounds by people who regard the weather in the light of a new proverb that what cannot be endured must (of course) be cured. That order of arrangement is not attractive to meteorological science because forecasting for half-hour stages by circulating, hour by hour, reports of the weather at each of the aerodromes on the way is too much like forecasting the state of the line between London and Edinburgh for the Scotch express; it degenerates or is apotheosised into signalling. It is an achievement of organisation and communication, not of true comprehension of the frowardness of weather.

Let us therefore begin on the larger scale and consider the mapping out of the air routes of the world. We may remember that the Atlantic has been crossed by an airship, both from east and from west, and by aeroplanes from the west by two routes, a significant difference.

Australia has been reached by the travel of an aeroplane from England in suitable stages: but the attempts to reach Cape Town were not so successful. The difference of the circumstances is expressed by the meteorological conditions incidental to height of the land in Central Africa. They were fairly well known before the attempts were made, but not sufficiently so.

For the mapping of the air routes of the world the distribution of pressure is the safest guide on the understanding that in the region where aeroplanes fly the air currents are along the isobars, and at those heights the run of the isobars is not very different from what it is at the surface. The normal change with height is, moreover, a legitimate object of meteorological study. We have shown the distribution at the surface in the charts of isobars of the globe in Figs. 9 and 10. The representation there given is not so expressive as it ought to be because Mercator's projection on which those maps are drawn gives a very misleading impression of the relation of northern latitudes where we live to the equatorial regions which we may have to cross. We will therefore replace them by the new figure for July (Fig. 11, p. 56) and add to the representation of the isobars a sufficiently probable representation of the normal winds deduced from them.

The subject of the air routes of the world, regarded from this point of view, was treated by Lord Montagu of Beaulieu in a lecture for the Royal Geographical Society on June 21, 1917, and, further, in a subsequent lecture by Sir Frederick Sykes, Controller-General of Civil Aviation, before the same society in 1920.

The selection of an air route on the basis of the prevailing winds as deduced from the distribution of pressure is not the only contribution of meteorology towards meeting the needs of aerial navigation over great distances. We have to supply particulars of the normal prevalence of cloud, rainfall and fog, which are of importance for navigation, as well as of temperature, pressure and density, which are of importance for engines. All these lie within the store of information from all parts of the world which every national meteorological organisation aims at including within its responsibility, and which finds expression in the choice, not only of the most suitable routes, but also of the most suitable season and the most suitable time of day for the various stages of the journey, by the study of the seasonal and diurnal variations of the meteorological elements.

These, however, go beyond the immediate purpose of the method of weather charts with which we are at present concerned.

That takes its place as a means of keeping the pilots of aircraft informed of the conditions of weather along the lines of route and the prospects of the more or less immediate future. It involves the extension of a common system of organisation for mapping and for drawing deductions over extensive areas that must in time cover the greater part of the globe and will require not only the intimate co-operation of the established meteorological services on land, but also the assistance of ships within the range of the shore establishments by wireless telegraphy, which can supply observations to be incorporated with the charts for the more frequented areas of the globe.

Such was the acknowledged position of meteorology at the end of the war that it was made the subject of an "annex" to the Treaty of Peace in 1919, which prescribed the general form of telegraphic reports required for charts suitable for the requirements of aircraft and the organisation of wireless telegraphy for exchanging them between the associated countries. The regulations prescribed the organisation of observations four times daily and the elaboration of the observations themselves in much greater detail than had previously been reached by international organisation. They also prescribed special observations of visibility on land and sea as well as of waves and swell at sea, and provided codes in which the new observations should be reported.

The new scheme is fairly represented by the information which is now contributed to the Daily Weather Report of the Meteorological Office and is shown in facsimile of the report which appears as Figs. 4, 5, and 6.

The hours chosen for observations are 1 h., 7 h., 13 h. and 18 h. G.M.T., so that maps are now drawn for intervals of five, six or seven hours. For the air routes the information is supplemented by observations every hour. Hence the meteorologists at the aerodromes are enabled to provide estimates of the present state of the weather along the routes and the prospects for two or more hours ahead, while the Central Office can provide in addition, forecasts for six hours or for longer periods up to twenty-four

hours, with a further outlook beyond that period, limited only by the inferences which the forecaster can draw from the maps, taken in conjunction with his experience of the behaviour of the weather in similar circumstances on record.

Thus the use of the weather maps, of which we traced the beginnings in our first chapter, promises to become a world-wide organisation in the special interest of aircraft worked upon a system common to all the meteorological services and furnishing material for maps of the whole globe.

CHAPTER XVI

FORECASTS FOR SEA AND AIR: VISIBILITY

Closely connected with the meteorological problems concerning aerial navigation is the difficult question of visibility. A scale for reporting the distance at which selected objects are seen at the reporting stations has been given already in Chapter I. The subject is equally important for navigation in its customary meaning as applied to the sea. There are many points of difficulty in connection with the relation between the distance of visibility and the meteorological situation which form the subject of a memorandum prepared for the Admiralty in 1918. Until the observations which are now being made at the meteorological stations and on board ships come to be collated and examined the subject cannot be treated on the basis of statistical results. But some guidance on points of interest may be useful. The memorandum of 1918 is therefore reprinted here, and a note by Mr. Charles Harding, formerly principal assistant in the Marine division of the Meteorological Office, is added, upon the results of an analysis of a large number of observations of visibility on the North Sea as the only available data based on observation.

In the memorandum the question of visibility is brought into relation with turbulence and mixing of the lower layers of the atmosphere, and the same physical process is invoked again in discussing the formation of sea fog in Chapter XIII., and land fog in Chapter XVII. It has been thought best to retain the full text of the memorandum and to ask the reader to excuse the repetition instead of attempting to bring both visibility and fog under one heading.

The question of the association of the variation of transparency of the atmosphere which governs the distance of visibility, with specified meteorological conditions, is a very difficult one. Its

study has never been incorporated into the ordinary work of meteorology and the whole subject of meteorological optics has been very much neglected in this country: no one has made it a special study although Dr. J. Aitken has made some contributions to it. In the Beaufort notation there is an assignment of the letter *v* to mean "unusual visibility" and Dr. Aitken has urged from time to time that a more definite meaning ought to be given to the symbol by meteorologists by giving the distance of visibility. But very much depends upon the time of day, the lighting and the surroundings of the observer at the time that he makes his observation, so much, indeed, that nothing but confusion would result from an endeavour to collect such observations in the ordinary way from the observers at the regular stations without careful preliminary instruction to secure co-ordination, that nobody is in a position to give. The unusual visibility which is indicated by *v* is differently defined by different writers; some regard it as meaning that the observer can see a great distance, and others say that by *v* is meant that distant (but not very distant) hills, with the details, look peculiarly *near* rather than peculiarly *clear* in the sense of being visible an unusually long way off. So far as I know, the observations of *v* at the various stations of the Daily Weather Service have not been collated. In a vague way the *v* is regarded as a prognostic of a coming depression; there is probably some authority for that, though I cannot quote it off-hand. The occasions of *v* could easily be taken out, and might usefully be so, but I think it would be necessary to go to the original sheets. In the Daily Weather Report I find it difficult to distinguish between *v* and *r*.

The question is a very intricate physical and meteorological problem. It is not possible to take it in the ordinary stride of a general Meteorological Office; it ought to be made the special occupation of some one who is very fully acquainted with the physics of the atmosphere and has experience of the sea as well as the land and opportunity for acquiring more. I have been asked from time to time by the Superintendent of the Marine Division to fix a scale of visibility according to distance, to be

used by the observers for the Office, but it has always seemed to me to come perilously near to fixing an observation by what you "cannot see." Every effective observation must be based upon what one does see, not upon what one does not, and a statement in effect that one cannot see another ship two miles off implies as a preliminary, the assurance that there is a ship to be seen. For example, as evidence in a court of law or for meteorological statistics, A. B., an officer of a certain ship, stating that on one occasion he was unable to see another ship two miles off and on another occasion he saw one, is not at all definite about the atmosphere.

Ultimately we arranged that our observers should note certain objects which they see as they pass at known distances and so deal with the matter on the basis of what is seen, not how far they can see. The observations have not yet been summarised and what I have now to offer may be taken as suggestions which may assist in making an effective classification.

TURBULENCE AND MIXING OF THE LOW LAYERS OF THE ATMOSPHERE

In dealing with visibility at sea we are concerned only with the lowest strata of the atmosphere, those quite close to the surface, therefore we ought to have always in mind a picture of the peculiar condition of the atmosphere there. The surface is a fixed boundary of all currents of air moving over the surface and the movement over the surface causes eddy motion or turbulence of very irregular character of which we now know a good deal from the work of Major G. I. Taylor. The energy necessary for the turbulence comes from the motion of the air. At a rough computation the velocity of the wind in the bottom layer is reduced by one-third over the sea and by two-thirds over the land. As the air flows on and on the effect of the turbulence reaches higher and higher according to a law which Major G. I. Taylor has formulated for otherwise undisturbed air. This turbulence or eddy motion means that the lowest layers of the atmosphere are always being mechanically churned up as long

as there is any wind—even when the wind is very light there is still eddy motion just as there are eddies near a ship's side when she is only just moving through the water. They are, in fact, better seen then than when she is at full speed and it is just possible that we may get a better idea of the turbulence of the atmosphere from watching the languid drift of air that we find in a fog—for a fog is never still—than by peering at the disorderly commotion caused by a strong gale going over sea or land.

This mixing of the lowest strata by the eddy motion due originally to the friction of the surface may be accountable for, and in its turn affected by many meteorological phenomena. It is indispensable for the formation of the normal type of sea-fog, viz., that which is due to relatively warm air moving over cold sea. It is probably accountable for the formation of layers of clouds over a large stretch of land or sea at an apparently perfectly uniform level. If we imagine, for example, a current of air like the north-east trade wind making a very long straight fetch and passing over gradually warmer sea: the air is always taking up more and more moisture and that is being churned and consequently getting so arranged that the air of the top is properly cold and nearly saturated—a little further churning results in condensation at the caps of the rolls. So perhaps we get the clouds which appear as trade-wind cumuli formed at a uniform level marked by the place where churning of the surface layers just begins to give condensation (Fig. 7).

The detached clouds known as "scud," or fracto-nimbus, which are often seen drifting underneath the dark nimbus clouds at the tail of a rain-storm, are probably also examples due to the condensation caused by the mechanical churning of the lower layers heavily laden with water-vapour in consequence of the rain on the warm ground.

Normal sea-fog is another case of cloud formed by churning, originally due to the effect of the surface but in a different way. That is caused by the mixing itself, not by the elevation which the turbulence ultimately gives to any particular specimen. When the sea is cold it chills the surface air, the turbulence stirs

up the chilled air and mixes it with the warmer air above. If the surface air is cold enough the result of the mixing is a cloud. If there were no churning and therefore no mixing there would be no cloud. The moisture instead of being condensed in the air itself would be deposited on the cold surface like the drops on a cold glass. So it is on land with fog and dew. If there is churning there may be fog, if there is no churning there may be dew but no fog.

CONVECTION IN THE LOWER LAYERS

The next point to be borne in mind in thinking of the causes of visibility and its opposite atmospheric obscurity, is the physical process known as convection because when convection is operative and vigorous the commotion of the air extends to great heights and any atmospheric pollution of a mechanical character, such as smoke or dust, is rapidly dispersed and diluted so that the visibility is maintained at a reasonable figure, whereas if the mixing due to turbulence near the ground is the only mechanical operation going on, and convection on the larger scale is prevented, the obscuring particles are kept within a comparatively thin layer and effectively obstruct the view.

Convection is usually described simply as the descent of air locally cooled in a warmer environment somewhere above the surface, or the ascent of warmed air (warmed, for example, by heated soil or sea) in a relatively unwarmed environment. The process is illustrated in the laboratory by warming water at the bottom and showing that the warmed water rises and is replaced by water cooler than itself, or by cooling the water at the top and showing that the cooled water sinks. Many illustrations drawn from indoor or outdoor experience are cited, the ordinary heating apparatus for hot water, the draught up a chimney, the general cooling of ponds, and so on. But in the atmosphere there is something else to be taken into account and that is the distribution of temperature in the air from the ground upwards, what is now called the " lapse " of temperature with height. It is this

distribution of temperature in the vertical which decides how far warmed air will rise before finding its level. The reason for taking into account this distribution of temperature is the so-called dynamical cooling of air on the reduction of its pressure. Air which is rarefied is cooled automatically, so that generally speaking in the atmosphere the air is colder the higher up it is. As it is brought from below where the pressure is higher it cools and as it descends to the higher pressure it gets warmer. If one imagines a mass of air to be completely churned up and in that way thoroughly mixed, the top is not at the same temperature as the bottom but is automatically colder to the extent of 10° C. for a kilometre or $5\frac{1}{2}$° F. for 1,000 feet. The air, when thoroughly mixed, would then be in what is called "convective equilibrium." If it were stirred up like a cup of stirred tea there would be no tendency for it to "settle," for the one part to sort itself out at top or bottom. But when it is in that state if the bottom be warmed by *ever so little* the warmed air will rise and always cooling at the same rate as its environment will always *go on rising* until it has got beyond the limit of the well-mixed air and finds a place where the temperature of the environment falls off less rapidly than that of the air as it rises.

There is, therefore, a maximum lapse of temperature, a rate of fall of temperature with height in air at rest, which cannot be surpassed, and when that limit has been reached the whole mass is in a very sensitive condition; any part that is locally warmed goes to the top without fail and any part that is locally cooled to the bottom. The bottom may be the ground and there is an end of it—the top evidently cannot be the ground; it is a place where the lapse-rate is less than the maximum and where the rising air can therefore rest. It is the more sure of resting there the greater the defect of the lapse from the limiting rate. A place where convection always stops is at the bottom of the stratosphere, from the beginning of which there is no lapse of temperature with height. Lower down in the atmosphere there are formed, from time to time, layers in which the lapse is reversed where the air gets warmer with height instead of colder. That is generally the

case from the ground upwards in a fog for some distance beyond the top of the fog. So there is no chance of convection in a fog. The layer of air in which temperature rises with height forms a sort of " lid " which cannot be penetrated by convection. Some time ago a friend of mine just returned from a balloon voyage told me that, in coming down, the balloon rebounded three times from a cloud layer. The rebounds were really due to the lid where, because the temperature was diminishing downwards while the pressure was increasing, the density got greater very quickly and the balloon coming downwards quickly into the denser air found itself over-buoyant and went up again.

A lid of this kind is generally, perhaps always, to be found in and above the stratus-cloud of anticyclonic weather. It also probably accounts for the cloud sheet of strato-cumulus that forms a level canopy and is often persistent the whole day at about the same level without rain. Such canopies or lids formed by a layer of air with reversed lapse or inversion of temperature-gradient, as it is sometimes called, are very important. We have seen that they are layers of very rapid changes of density so that the atmosphere takes on a condition more or less analogous to oil on water. They are, therefore, layers of separation between parts of the atmosphere. The convection of warm air cannot penetrate the lid from below nor can that of cold air from above. The winds may be entirely different above and below both in direction and force. There is no mixing between one side of a lid and the other.

The atmosphere of a cyclone can be differentiated from that of an anticyclone by the fact that as a rule the lapse of temperature in a cyclone is very close to the limit whereas in an anticyclone it is often far from it. Very little warming, therefore, is necessary to produce a great convective commotion in the air of a cyclone, but a great deal is required in an anticyclone. Generally there is no " lid " to a cyclone until the great general lid, the stratosphere, is reached at 30,000 feet, more or less : in an anticyclone an intermediate lid is often to be identified. It can even be seen, for anticyclonic cloud is sure evidence of a lid, so also is fog. Generally,

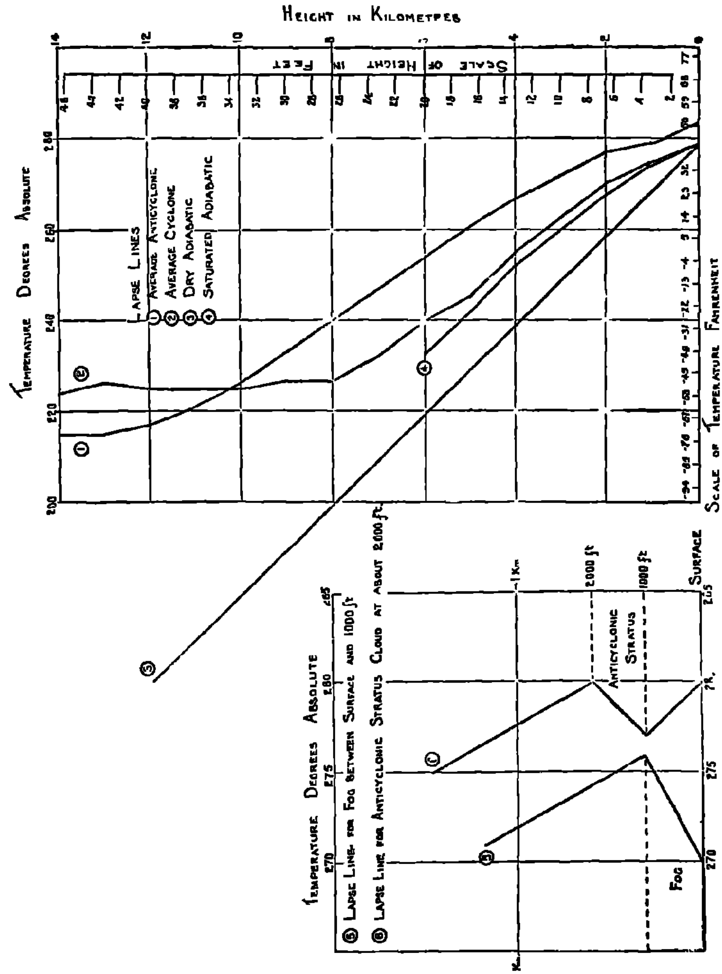


FIG. 170.—Typical Lapse Lines and Adiabatics for Dry and Saturated Air.

after a clear night a lid lies on the ground itself and if it goes so far as to form fog the lid may stay on the ground all day. But in the day-time in sunny weather the surface air may be so churned, by wind and warming, that a layer of mixed (or isentropic) atmosphere, with the limiting value of the lapse may extend upwards from the ground for a little way and then stop at a lid—an inversion of temperature-gradient—an increase of temperature with height—that stops further convection.

These remarks on the structure of the atmosphere in relation to convection can be summarised by a diagram (Fig. 170), representing a series of typical lapse lines. On this diagram Curve 1 represents the normal lapse line when the surface pressure is high, Curve 2 the corresponding data when the surface pressure is low. Curve 3 represents the limiting lapse line for an atmosphere consisting of perfectly dry air. Curve 4 the corresponding curve for air which is saturated with water-vapour at the temperature of 278 t. (5° C., 41° F.). The great permanent "lid," the stratosphere, is indicated by the bend at 8 km. 26,000 feet in the "cyclonic" curve. Curve 5 shows the detail near the surface in the normal production of fog and Curve 6 shows the corresponding detail when there is stratus cloud about 1,000 feet up.

In this discussion the word "lid" has been used to indicate the impenetrability of a layer in which temperature is nearly uniform or increases with height. For mathematical purposes V. Bjerknes classes it as a "discontinuity." "Ceiling" would be an expressive word, but it has already a technical meaning for aircraft, denoting the highest level which the particular machine can attain. After consideration I have come to the conclusion that the idea conveyed by the word "deck" is the most appropriate. If we consider the stratosphere as constituting the "main deck" of the atmosphere, we may contemplate the existence of "lower decks" within the troposphere wherever there is an inversion lapse-rate or a near approach thereto. The one objection is that in the case of fog we have a "deck" lying on the ground or on the sea. We are no better off with lid or ceiling, and as the image of

a layer impenetrable in ordinary circumstances is of great assistance in considering the atmosphere, we prefer to use the word "deck."

THE ELEMENTS OF ATMOSPHERIC OBSCURITY

Let us next consider the elements of which atmospheric obscurity is made, and first run through the circumstances in which seeing is bad.

1. A really thick fall of snow or a dust storm.
2. Fog in its various degrees of density.
3. Drizzling rain.
4. Heavy rain.
5. The smoke cloud of manufacturing cities.
6. The mixed cloud of smoke and water-drops possibly due to the action of sunlight on the products of combustion of fires and furnaces.
7. The thin obscurity which is often logged as mist at sea and which obliterates the horizon. It may be due either to a very thin cloud of water or to dust, haze or smoke.
8. The thin cloudiness that is often noticeable after heavy rain on warm earth.
9. The splash and spray of breaking waves.
10. The shimmer of a hot road in the sun on a bright calm day, or of a hot funnel or stove.

It is evident that there are here three different ways in which seeing can be spoiled. (1) by the drops of water or ice in the form of clouds including fog, snow or hail; (2) by the mechanical loading of the atmosphere with soot or dust, volcanic or other, to which we may add the possible condensation of drops due to the indirect action of furnace fumes: (3) the optical deterioration due to striation in the air in consequence of the mingling of portions of unequal density. First, let me remark that the effect of any kind of obscurity except the last depends very much upon the way in which the illumination falls. If a searchlight is turned upon a tumbler of soda water in active effervescence the water will be seen to be capped by a cloud quite sufficient on the large

scale to spoil the seeing. It is formed by the droplets thrown up by the breaking bubbles. Whereas, ordinarily, when the illumination does not come from behind or across, no interference with vision is noticed. There are all sorts of variety of this effect. The light from behind may make a dark object invisible by the blind-screening effect of the illuminated particles in front of it, but it may make a white object the better visible by the additional illumination obtained from it.

These and similar circumstances have to be taken into account when assigning causes to the difference of visibility on otherwise similar occasions. One general remark may be made here, that the more minute the subdivision of the substance which causes the obscurity the worse is the seeing. I was curious one day at St. Ives to watch how fluctuating the visibility of Godrevy lighthouse was during a rainy day. On the following day there was a fog of very variable density, but there was no seeing the lighthouse at all. The lightest fog was worse than any rain of the day before. It was curious that on the fog-day one could either see the lighthouse clearly or not at all. A mere wisp of fog obliterated everything, but the rain only made it gradually more and more indistinct. The fog looked white but the rain never did. Perhaps when a searchlight is turned on to its object in a rainstorm it makes the rain visible and not the object. The experiment must often have been tried and the result is probably well-known.

SMOKE OBSCURITY

Coming now to the mechanical obscurity due to soot or other solid fragments hereinafter referred to as pollution it may be remarked that the combined effect of many chimneys and funnels spoils the seeing of a good deal of atmosphere. In the first eight months of the war the atmosphere of Oldham gave a deposit at the rate of 250 metric tons per square kilometre; the rate for Malvern is 16 tons for the same period, so that at the best there is a good deal and at the worst about fifteen times as much solid matter in the atmosphere over the land. It goes, of course, down wind. I have known occasions

when the seeing was thoroughly well spoiled by London smoke forty miles away and by Glasgow smoke fifty miles away. Volcanic eruptions have been known to affect the seeing all over the world and a dust cloud from Africa has been known to make good seeing impossible to steamers, not only on the South African, but also on the South American route. The travel of smoke obscurity is very different on different days. In brisk cyclonic weather when, as we have already seen, convection is active to an almost unlimited height, the smoke is carried away and produces little noticeable effect to the observer who is not specially inquisitive; whether the effect can be noticed in the stricter scrutiny of a ship on patrol I do not know.

The atmospheric condition which prevents the smoke getting away freely and causes the obscurity to travel a long way down wind is the existence of what we have called a lid, "deck," or canopy. Where there is a canopy (represented on our diagrams by reversed lapse, or increase of temperature with height) the smoke spreads out under the canopy and is churned up by the turbulent motion and so kept within the limits of the layer. Probably during a fog in London when there is a marked reversal of the lapse of temperature the smoke of London chimneys is all retained within a layer of about 300 feet (this figure is based upon the fact that Hampstead can sometimes look down on the top of a London fog). The limits are wider but they are still there on an anticyclonic day with stratus cloud above, somewhere between 500 and 5,000 feet. In an excellent paper in the "Proceedings of the Royal Society at Edinburgh" "On some Causes of the Formation of Anticyclonic Stratus as observed from Aeroplanes," Captain C. K. M. Douglas, R.A.F., speaks of this kind of cloud being "typical in form for the northern and eastern sides of anticyclones." How far it may be regarded as limited to these parts further observations could show perfectly well.

The practical conclusion is that with any sort of land wind, at any rate, really good seeing is not to be expected under anticyclonic stratus or clouds of similar type in consequence of the fact that all the pollution is kept confined below the cloud layer.

"The lower the cloud layer the worse the chance of seeing, because the dilution of the smoke is less. On the other hand cyclonic weather with its strong convection is from that point of view good for seeing and the appearance of cumulus clouds in the sky ought to be a good sign, as showing that there is at least some convection there.

OPTICAL DETERIORATION BY STRIATION

How far the striation of the transparent air by the juxtaposition of layers of different density is a real cause of bad seeing I have not enough evidence to say. The seeing is often bad in the sultry weather which precedes a thunderstorm. I remember one occasion on the low plateau near St. David's when the atmosphere was simply murky in meteorological conditions not specifically different from those which had given quite good seeing weather with gradual rise of mean temperature during the preceding three or four days. I had no instruments, but there was nothing to suggest that the air was damp; dust or smoke may have come with the wind from the South Wales coalfield lying to the eastward—looking back, probably it did under a low lid, but at the time I could think of no other cause than irregular refraction. Those who have experience of desert conditions would have more information than I have on this point.

WATER DROPS

We come now to the main meteorological cause of bad seeing over the open ocean, the water drops in the surface layers. The sketch of the probable course of events in the case of normal sea-fog is now nearly completed; we know that the preliminary condition for the formation of fog is a lid of air lying on the ground in which the lapse of temperature is negative, that is, temperature increases with height. A cold surface for the sea or a wet surface for the land and enough motion of air over the surface to churn up the bottom layers, no matter how slowly, is the full story. Fog is in general a summer visitation over the

ocean and a winter one over land. For the coasts of the British Isles a line from Scilly to Leith separates more or less the region of summer fogs on the west from that of the winter fogs on the east. The type of fog formed by the turbulent motion of relatively warm air over cold water has been called "normal sea-fog" here because it is believed that sea-fog is generally produced in that way, but it must be allowed that the opposite conditions, namely, cold air over warm water, may cause fog at the surface, and clouds, possibly thunder clouds, higher up. When a spell of cold weather sets in, in autumn or winter, ponds which are for the time being relatively warm are often covered with "wreaths" of steam. I have never seen the sea "steam" in the same way, but have been informed that it does so (see p. 391). The physical process is complicated; there is the evaporation of the water at the warm surface and re-condensation in the air after the mixing of the warmed saturated surface layer with the colder environment. The mixing is partly the result of convection, partly of turbulence. The "success" of the experiment depends upon the water at the surface being evaporated faster than the air in the layers above can take it up, and that again upon the humidity and temperature; so the process seems more capricious and uncertain than the normal or cold water-fog. In either case real fog draws a very easy distinction between good seeing and bad seeing; fog is the end of seeing for the purpose of patrol.

There is, finally, that perplexing form of deterioration which is not thick enough to be called cloud or fog, and which blurs outlines and makes seeing bad at a distance; the condition of things which our marine observers call mist. The name which fits the conditions best is perhaps *nebula*. Sometimes it is certainly pollution, but there are occasions on which perhaps it must be attributed to water drops. In the "Meteorological Glossary" under "Clouds, Weight of," it is stated that the weight of water suspended in clouds is from ·35 to 4·8 grammes per cubic metre. We have to recognise the possibility of there being less water in the condensed form than ·35 g/m^3 and therefore not enough to form a cloud, and yet more than enough to saturate the air by

something less than one-tenth of what goes to make the thickest cloud.

I do not think that laboratory work teaches us how to produce a nebula of this kind, but it tells us that it can only be produced in saturated air (there is a suggestion that it may conceivably be produced in unsaturated air by the ultra-violet light of the sun, about which see p. 441), and it tells us also that it can be completely got rid of by a very little increase of pressure. The sudden transition from the "murky" to the "very clear" in a glass globe when the pressure of air containing cloud is slightly raised is most striking. All at once the change takes place and the compressed air becomes conspicuously transparent.

On the other hand theoretically when the air is saturated the smallest diminution of pressure will produce some condensation into water drops and consequently some deterioration of the seeing which will become continuously worse as the pressure is continuously reduced. There seems no reason to suppose that this is not true in fact of the atmosphere whenever saturated air is passing through a series of changes of pressure. In a memoir on the "Life-history of Surface Air-currents" (M.O. publication No. 174, 1906) Mr. Lempfert and I traced the course of the air along the surface in a considerable number of typical barometric situations and we found that in a well-formed circular depression or in a V-shaped depression all the air in front of the trough-line was moving so that its pressure was constantly diminishing and all the air at the back of the trough-line was moving so that its pressure was constantly increasing so long as it formed part of the depression. Diagrams showing the variations of pressure which amounted in each case to something like 15 millibars are given in the frontispiece to M.O. 174, and we may certainly conclude from these considerations that we may divide the region covered by a depression into two parts as in the figure by the lines AOB for the cyclone and AB for the V-shaped depression (Fig 171). In the front, pressure is diminishing, condensation approaching or occurring, visibility deteriorating; in the rear, pressure is increasing, cloud disappearing and visibility improving. If the labora-

tory experiment is a real guide to what takes place in the atmosphere the rear of a cyclone or V-shaped depression ought to give the best of seeing for the reasons stated. This seems to be a sufficient explanation of the clear air in the north-westerly wind in the rear of a cyclone or V-shaped depression. In a circular cyclone during the early stages of the process of clearing, that is, in the north - west quadrant, the improvement of the seeing is interfered with by rain which falls in that region, so we have to wait for the clear air until some time has elapsed after the trough has passed. In the V-shaped depression the transformation is much more sudden because the rain is over very soon after the trough has passed.

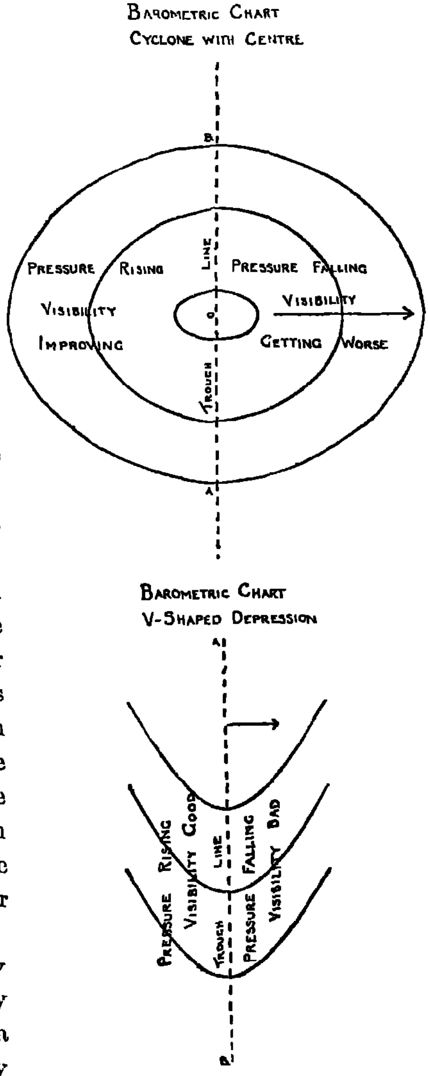


Fig. 171.—Relation of Visibility to Barometric Changes.

Here, then, is possibly the key to the brilliantly clear air that comes as a rule with the northerly or north-westerly wind in the rear of a depression or shortly after the passage of the trough of a V.

RELATIVELY DRY AIR

Condensation can only take place if the rarefaction is continued up to and beyond the saturation point. It need hardly be said that when the air is cooled by rarefaction its relative humidity is increased and the saturation point is approached and passed if the rarefaction is pressed far enough, and, on the contrary, so soon as the pressure on saturated air is increased the drops begin to evaporate, and after the evaporation is complete the air becomes dry under the continued increase of pressure. So when the air has become clear it is also relatively dry and continues to get drier as the increase of pressure continues. The north-west wind of a cyclonic depression is well-known to be a dry wind. Perhaps the material of which it is composed is dry to begin with, as it may be a substitute for the wind which enters the cyclone from the south and west and forms the eastern part of it. It certainly gets drier as its pressure increases.

So we are led on to consider relative dryness of the air as a condition of clearness. Dryness is undoubtedly a favourable circumstance, and if dry air could be protected from pollution we might trace a direct connection between dryness and clearness. The driest of our winds come from the north-east or east. They ought on that account to be very good seeing winds, but they belong mostly to the eastern or south-eastern sectors of an anticyclone and probably have a lid to them which prevents any atmospheric pollution from getting away. Hence north-easterly and easterly winds must be regarded with suspicion as good seeing winds on the western coasts or near thereto. It is possible that they may be good over the more northern part of the North Sea if the air is not too much contaminated before it leaves the opposite shore. In the southern part of the North Sea the eastern shore is too near and the region from which the wind then comes is the region which provides characteristic examples of the weather symbol *z*. But, once more, these are only suggestions and require confronting with a proper series of observations.

The considerations here set out lead to the conclusion that the best seeing weather ought to be that which comes with a north-west wind in the rear of a depression because we know that the air is in that case moving towards higher pressure. But there are many cases when the weather cannot be so definitely associated with a travelling depression. Our ordinary weather is associated with maps of no very definite type. Nevertheless, the pressure of any sample of air certainly does vary, sometimes from causes which are far more general than the local peculiarities of our maps and are with some reason attributed to changes taking place in the upper air, about 30,000 feet up. For example, between July 27 and 29, 1908, the pressure over the British Isles, especially in the eastern part, increased by about 10 mb. by the intrusion of a mass of cold air at that high level over the Islands. That ought to have improved the visibility over the region affected by the increase of pressure. So it may be possible to get good seeing weather, in the circumstances of which those are an example, as a sort of gratuity from changes in the upper air.

Apart from these and similar cases let us revert to the position that the best chance of seeing comes with air which is making for higher pressure. It would seem that those are the occasions when *à priori* one would expect the symbol *v* to be logged for unusual visibility. How the association would work out in relation to the advance of another depression is one more point that needs further enquiry. My own impression is that until the barometer begins actually to fall and the depression may be said to have arrived the air may be undergoing increase of pressure, but the question requires to be examined by noting the history of the air logged as *v* in its immediate past. It is not a difficult investigation and should prove interesting.

ULTRA-VIOLET LIGHT

Before summarising the conclusions reference ought to be made to various experiments of the physical laboratory in connection with the condensation of water drops in air which is not saturated with water-vapour. There are certain experi-

ments by Mr. C. T. R. Wilson which explain the circumstances in which a deposit can be obtained in air which is free from dust. The rarefaction can be pressed until water condenses upon the free ions as a substitute for the " dust " particles which were proved by Aitken to be necessary for condensation in the ordinary way and of which, so far as we know, there is always an adequate supply in the atmosphere. These experiments are sometimes quoted in meteorological text-books and memoirs as providing for the condensation of vapour in unsaturated air. That is not the case, because in Wilson's experiments condensation only occurred when a state of " fourfold saturation " was reached, that is to say, the condensation took place not in relatively dry air, but in air which was highly *super-saturated*. But a further experiment of Wilson's showed that a beam of ultra-violet light caused a cloud of deposit in ordinary saturated air, and I learn from Major G. I. Taylor that a concentrated beam of ultra-violet light causes a cloud to form in air which is not completely saturated with water-vapour.

The application of this experiment to the atmosphere is another point which requires to be worked out. The suggestion is that as the sun's rays are relatively rich in ultra-violet light before it is absorbed by the atmosphere, the solarisation of the air *may* conceivably cause condensation in unsaturated air in the atmosphere. But so far as the visibility in the surface layer is concerned there is a gap in the reasoning. The upper layers of the atmosphere have some water-vapour in them, and they certainly absorb a good deal of the available supply of ultra-violet light, and the sunlight that reaches the surface is not the kind of radiation that is chosen for the experiment in the laboratory. What we require to know before we can decide the question is whether a beam of sunlight passing through a sample of ordinary unsaturated air at the surface, for as many hours as the sun is above the horizon, will actually produce a cloud. The reason for requiring further investigation before accepting the ascertained effect of ultra-violet light as a true cause of condensation in the lower layers in the sense applicable in meteorology is the apparently capricious

relation of the observed effect to the supposed cause. The distribution of the sun's rays over the earth is very regular and very impartial, but the formation of the light condensation that spoils the seeing is very local and very irregular. The situation may, with complete fairness, be stated thus, that for any case in which the condensing effect of sunlight is suggested, in the absence of other sufficient reasons, as a cause of condensation in the atmosphere, innumerable cases can be cited from every part of the globe in which sunlight produced no condensation.

OTHER CASES OF CONDENSATION IN ABNORMAL CONDITIONS

The *formation of water drops by condensation is certainly* affected by physical conditions. The cloud of steam which issues *from a boiler through a nozzle throws a different kind of shadow* when the fumes of burning gas are allowed to foul the jet and the electrical condition of the air in the neighbourhood of the jet also produces an effect, but none of these effects seem to produce condensation in circumstances in which otherwise no condensation would occur, that is to say, in unsaturated air. Actual globules of acids or salts may enlarge themselves by the absorption of water, and once formed are not easily got rid of. Reference has already been made to Aitken's observations upon which he based an explanation of the prevalence of city fog some time after sunrise, by supposing that acid fumes caused condensation in the presence of sunlight.[1] That is the only case of condensation above the dew-point which is known to me as supported by direct observation.

SUMMARY.

I may now summarise the conditions of good and bad seeing and the corresponding meteorological conditions according to the considerations set out in what precedes, omitting any reference to ultra-violet light as being beyond my knowledge. I will arrange them in order with their causes and with some remarks about them.

[1] "Proc. R. S. Edin.," vol. 31, 1910—1911, p. 478.

	Specification	Causes	Remarks
	GOOD SEEING		
1*	The rear of a travelling cyclone in the sectors of the northerly and north-westerly wind	The continuous compression of the air causing evaporation of drops and subsequent drying; high convection coefficient	Can be spoiled locally though only partially by urban pollution and may suffer somewhat from spray at sea
2 †	Other places over which the pressure has recently become normal and is still increasing owing to changes in the upper air	The same without the high convection coefficient	Spoiling by atmospheric pollution is not unlikely
3* †	Easterly or north-easterly winds with high cirrus moving from same direction	Dry air and adequate convection coefficient	Liable to be spoiled if the air is cold and passes over a warm sea or somewhat spoiled by pollution and also by drizzling rain
4*	Calm air in summer in the central region of an anticyclone or a wedge between two cyclones	Rather variable, much better in the day when there is convection than in the night when there is none	One of the most uncertain types. Sometimes spoiled over land by shimmer
5*	Westerly wind	Moderately dry air very changeable and uncertain. Good convection coefficient	Spray and a tendency to fog
6* †	Easterly or north-easterly winds with stratus cloud indicating a lid	Dry air but no adequate convection coefficient. Very poor if in the outer margin of an anticyclone	Almost certain to be spoiled by pollution
7*	Southerly wind South-westerly wind	Changeable Reasonably good on the outside of a depression where the air is dry but tending towards saturation, cloud and rain nearer the centre. If it belongs to passing anticyclone it may be very good with good convection coefficient	The air is generally on its way to the centre and the conditions are favourable for mist
8*	South-easterly wind	Very irregular. Structure liable to fluctuations of temperature in the vertical	A transient condition meteorologically combining the disadvantages of 6 and 7
9*	Central region of cyclone	Rain and mist, pressure diminishing	
10*	Calm air in winter in the central region of an anticyclone	Cold surface and no convection, very liable to fog	
	BAD SEEING		

NOTE.—The conditions marked * can be forecasted, those marked † cannot.

This summary will make it clear why this subject cannot be adequately dealt with by the ordinary meteorological process of methodical observations, by a variety of observers, classification and "meaning." The state of visibility depends not only on the

conditions at the time of observation, but also on what has gone before, the geographical locality in relation to pollution and the structure of the upper air. If one had a recognised scale of visibility an observation high up in the scale might be followed by one quite low down for the same locality because the incidental circumstances might be quite different. Conditions which tend to produce a fog may just fall short of reaching the necessary limit and there may be good seeing followed almost immediately at the same spot by absolute screening.

OBSERVATIONS ON THE NORTH SEA

Observations made on ships in the North Sea during the years 912–1914 were reported to the Meteorological Office for examination. They were tabulated and discussed by Mr. Charles Harding. The observations gave the *distance of visibility* and were classified, first, according to the meteorological situation at the time; secondly, according to the wind-direction; and, thirdly, according to the hour of observation. It is noted that "the individual observations vary considerably among themselves, although the mean values greatly eliminate the variations."

The summaries in their most compendious form, are as follows:

1. VISIBILITY AND WEATHER CONDITIONS.

	Mean Visibility in Miles.	Number of Observations.	Resultant Wind-direction.
Wedge	12·2	390	353°
Anticyclone	11·5	652	36°
Col	8·5	167	338°
V-shaped depression	7·7	168	172°
Cyclone	7·3	648	210°
Straight isobars	6·9	22	157°
Secondary	6·6	202	210°

2. VISIBILITY AND WIND-DIRECTION.

Wind.	Mean Visibility in Miles.	Number of Observations.	Wind.	Mean Visibility in Miles.	Number of Observations.
N.	11·0	381	S.	7·7	394
N.E.	11·2	305	S.W.	8·2	318
E.	10·2	222	W.	8·6	259
S.E.	8·9	196	N.W.	9·8	150

3. VISIBILITY AND TIME OF DAY.

Time of Observation	Visibility in Miles	Number of Observations
One hour after sunrise . .	9	451
Noon	9	823
One hour before sunset . .	10	550

The uniformity of the figures in the last table is very striking. It could hardly be equalled by the corresponding observations on land.

PENETRATION OF LIGHT INTO THE SEA[1]

M. Helland-Hansen, as the result of observations in the course of a cruise to the south and west of the Azores, gives the following results:

Luminous rays penetrate as far as 100 metres, but at this distance the red rays are more reduced than the violet. At 500 metres the liquid layer absorbs all the red rays, and the fish of these regions, if anything, only see blue. A photographic plate is still affected. At 1,000 metres the violet and ultra-violet are still appreciable. At 1,700 metres there is no longer the least trace of light.

[1] "La Revue du Ciel," 2nd Année, November, 1917.

CHAPTER XVII

FORECASTING LAND FOGS

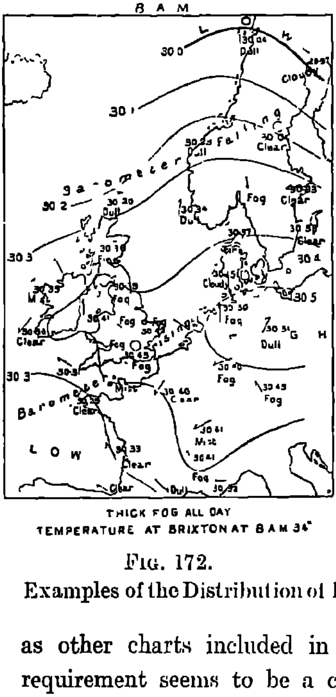
We have seen that we may regard the central region of an anticyclone as a laboratory in which, according to circumstances, nearly all the operations of weather may be exhibited on a mild scale, the outstanding fact remains that it is a region of calms or light airs, and in consequence anticyclonic conditions are specially favourable for the development of land fog—so much so, that an autumn anticyclone is nearly always accompanied by fog on land.

In the publication of the Meteorological Office on "Barometric Gradient and Wind Force," Col. Gold has shown that steep gradients and strong winds are inconsistent with the conditions of steady motion along isobars having anticyclonic curvature. It is curious but undeniable, that when a westerly current has an easterly current upon its southern side, the two show no disposition to mix except possibly to produce fog; they keep an undisturbed anticyclonic region between them as a sort of buffer state. If the westerly current has an easterly current on its northern side, quite the opposite state of things results—the two currents engage one another forthwith, and a circular storm results. Doubtless the consequences are in accordance with the principles of circulation and its acceleration laid down by Professor V. Bjerknes ("Monthly Weather Review," October, 1900), but to those unfamiliar with the reasonings of hydrodynamics they must seem rather mysterious. The path which is followed by the air in anticyclonic currents agrees perhaps more nearly with the undisturbed path of a projectile over a moving earth than anything else in nature, and we may almost look upon an anticyclonic region as one which is left

for the time being undisturbed by anything except purely local actions. These conditions are certainly favourable for the development of fogs. Two examples (Figs. 172, 173), taken from Captain Carpenter's Report to the Meteorological Council upon Fogs in London during the winter of 1901–2, will illustrate this. Fog forms under other barometric conditions,

A HIGH RIDGE 5 NOVEMBER 1901

8 A M

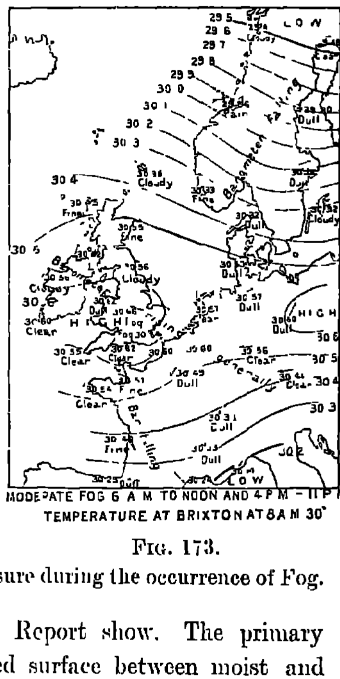


THICK FOG ALL DAY
TEMPERATURE AT BRIXTON AT 8 A M 34°

FIG. 172.

ANTICYCLONIC 25 NOVEMBER 1901

8 A M



MODERATE FOG 6 A M TO NOON AND 4 P M – 11 P M.
TEMPERATURE AT BRIXTON AT 8 A M 30°

FIG. 173.

Examples of the Distribution of Pressure during the occurrence of Fog.

as other charts included in the Report show. The primary requirement seems to be a chilled surface between moist and relatively warm ground below and nearly stagnant warm air at some distance above, yet with sufficient drift of the air over the ground to cause the mixing of the air chilled at the surface with the warmer moist air by eddy motion. Generally speaking, the gradual drift which promotes this mixture and consequent condensation in the air is the gradual drainage of the air to lower levels. Hence, fog forms in those parts of an anticyclone in which there is practically no gradient wind. The morning is the most

favourable time for its formation because, if the sky has been clear, radiation during the night will have reduced the temperature of the objects on the surface of the ground, and a cold layer of air will be found there and slip downwards along the slopes. The mixture between this surface-layer and the super-incumbent warmer atmosphere is limited by the extent of the eddy motion. In the absence of any pressure gradient there is only the katabatic air current on the sloping surface,[1] and we get what may be called a pond of surface air in valleys, generally forming part of an anticyclonic region, but left entirely to its own local actions without any extraneous disturbance. The process of gradual formation of fog in this way, filling the valley of the Lake of Coniston, in Lancashire, was carefully worked out by close investigation by Professor J. B. Cohen.[2] It seems to account for the local formation of land fogs on many occasions, and of the evening mists of the lower reaches of valleys. The process is apparently similar to that described in Chapter XIII. in the explanation of sea fog, but it is complicated by the fact that the cold surface is only temporary and the flow is due to gravity.

An examination of the records of the observatories shows that in inland districts the autumn nights give an atmosphere on the average more nearly saturated with moisture than any other time. This is partly due to the frequency of rain at night in the autumn, but partly also to the fact that the ground is, on the whole, warmer than the air, and evaporation is taking place. Hence, fogs would generally be forecasted as accompanying anticyclones in the autumn.

There are, however, occasions on which nearly the whole of the British Isles is covered with fog, lasting for hours. An example is given in the map for January 31, 1918 (Fig. 160). It is hardly reasonable to attribute this enormous production of fog-laden air to the cooling due to radiation from the elevated parts of the country. It seems more likely that in these cases

[1] A katabatic air current is one which flows downhill, like a cataract, in consequence of its component air being heavier, through local cooling, than the air beneath it ("Meteorological Glossary," M.O. Publication, No. 225 ii.).

[2] "Quarterly Journal Roy. Met. Soc.," vol. 30, p. 211.

of widely spread land fog, there is a gradual drift of a southerly current from the ocean landward, over regions that have been previously cooled by air from the cold east. The gradual drift causes the necessary mixing of the surface layers that is produced in the case of valley mists by the slowly descending current, due to local cooling.

It is also possible that there is mixing between the two currents from opposite quarters, generally of different temperatures, which form the northern and southern boundaries of the central region of an anticyclone.

Sea fogs may be of this character too, but more frequently, as we have seen, they are due to the slow passage of warm air over cold water.

THE FORMATION OF LAND FOG

We learn from G. I. Taylor's discussion, described in Chapter XIII., that the process of formation of land fog may be assigned to physical causes identical with those which are generally regarded as operative in the case of sea fog. Both are to be attributed to the cooling of the air within some considerable distance of the surface by the mechanical process of mixing with it the surface air cooled by the effect of radiation to a clear sky. Here we make a slight departure from the position taken up in the first edition of this book, wherein we supposed the process in the case of land fog to be the moistening of the valley air by evaporation from the warm, wet ground and its chilling by the cold air which descends to the valleys, because it is colder than the air which is already there.

It may be remarked that on clear nights when cooling takes place by radiation from the ground or the objects near it, temperature gradually gets lower the further down one goes. It is not necessary to suppose that the descending air forces the air in front of it upwards; we may regard it simply as part of a flowing stream. Hence, both for sea fog and land fog we may regard the surface as the region at which heat is lost by the air and the condensation as due to the mixing of the cooled air with the

warm air above it through the operation of eddies which are present even when the flow is very slow.

Yet we must not lose sight of the fact that the ground itself may be warm and may provide by evaporation the moisture which is condensed in the fog. That seems to be the immediate explanation of the prevalence of the mists and fogs of autumn. A layer of grass or herbage would provide for the process of cooling and evaporation might still go on from the ground. The process is certainly more complicated than in the case of sea fogs where the water, with its well-defined temperature, gives us a very clear starting point, and the flow of air over the cold water is in accordance with the distribution of pressure whereas in the case of land fog the motion is due to the downward drainage of cooled air. Yet we may look upon the process as dynamically the same in both.

THE DECK OVER A FOG

One other important result follows from this method of regarding the formation of fog. We have seen that the result of the eddy motion over the surface is to reduce the temperature of the stream of air from above downwards and to give us a layer of air in which the temperature increases upwards. Such a layer represents a condition of great stability as contrasted with the instability which results when the temperature falls off with height at what is called the adiabatic lapse-rate (see p. 213). If air penetrates the environment above it, it necessarily cools at the rate of 1 t. for 100 metres. Cooling at that rate combined with mixing with the surrounding air makes it practically impossible for air to penetrate automatically the layers above it and "get away" if the temperature of the air which forms the environment of the warmed air increases with height. The effect, therefore, of the process of fog-forming, that is, of making a layer in which there is an increase of temperature with height or an inversion of lapse-rate as it is called, is to place a canopy or deck overhead through which no air can escape. The first result, therefore, of the fog process is to set up such a canopy or deck overhead,

and as the process of mixing goes on we get the smoke of all our chimneys mixed with the surface air and rigorously confined below the deck. Hence, a common experience of foggy weather, even of weather of the same type that does not proceed to the extremity of fog, is for the smoke to be mixed up with the surface air unable to escape, as it does under more favourable conditions when the eddy motion carries up warm air from the ground and brings cold air down.

This process of the formation of an impenetrable layer or deck is one of the most important features of the atmosphere. The most conspicuous example is to be found in the stratosphere, the region in which there is no fall of temperature with height and which therefore surrounds the earth with an impenetrable main deck as represented in Fig. 12. It begins at 7,000 or 8,000 metres in the polar regions or in cyclonic depressions, but only at 17,000, or 18,000 metres at the equator and perhaps also over the great continents in summer.

In an ordinary London fog we may suppose that the deck or canopy extends to some height above the fog itself, perhaps to double the height of the fog. This would give us a height of about 200 metres for the commencement of the normal fall of temperature with height.

FORECASTING FOG

From the process which is thus indicated, and an examination of the records of the meteorological conditions which preceded the occurrence of fog at Kew Observatory, Richmond, in the years 1900—1905, G. I. Taylor has been led to consider the possibility of forecasting fog during the night with the aid of meteorological observations in the evening. The first step is to regard the formation of fog as due to the mixing of cooled surface air with the layers above by the diffusion due to eddy motion. It follows from the diagram of Fig. 84 which expresses the result of mixing air at different temperatures, whatever be the cause to which the mixing be due, that fog will be formed if the line joining the initial and final conditions cuts the curve of saturation. If,

therefore, the surface is sufficiently cooled and the mixing is active enough to carry the point representing the mixture beyond the saturation curve, but not sufficiently active to place the mixture beyond the second point at which the mixture line would cut the saturation curve, there will be fog. We may first consider the latter point. If the wind is sufficiently strong the mixing will be so vigorous that the warmth of the upper layers will disperse the cold air of the surface without causing condensation. Out of seventy occasions when fog occurred at night in the six years under consideration none was found when the wind exceeded nine miles per hour at midnight, and only eight when the wind at midnight exceeded 3·3 miles per hour. On only two of the occasions of fog did the wind exceed five and a half miles per hour at 8 p.m.

Taking, then, a wind of 5·5 miles per hour as the limit, the lower side of which may be taken as identifying a "calm night," we next require a clear sky in order to obtain the low temperature at the ground by which the condensation must be effected, and, thirdly, sufficient moisture in the air to bring the upper end of the mixture line close enough to the saturation line for the mixture line to cut the curve. For this we must know the condition of the air as regards moisture. This can be obtained from the readings of the wet and dry bulbs. Taking the depression of the dew-point at the time of observation (8 p.m.) as one co-ordinate on a diagram and the temperature of the air as the other co-ordinate, Taylor found that the diagram could be separated into two areas by a line giving temperatures corresponding with depressions of the dew-point such that fog was not at all probable on the dry or cold side of the line, the odds being thirty-one to three against, and on the moist side of the line the chance of fog would be about equal. A similar line was found to represent the conditions in like manner at Oxford, Nottingham and Potsdam. Upon this basis a fog-prediction diagram was constructed which is represented in Fig. 174. It consists primarily of a series of curves which represent the depression of the dew-point for assigned readings of the dry and wet bulbs (these are represented by full

lines in the diagram); crossing them are dotted lines which separate the conditions at specified times when fog is improbable

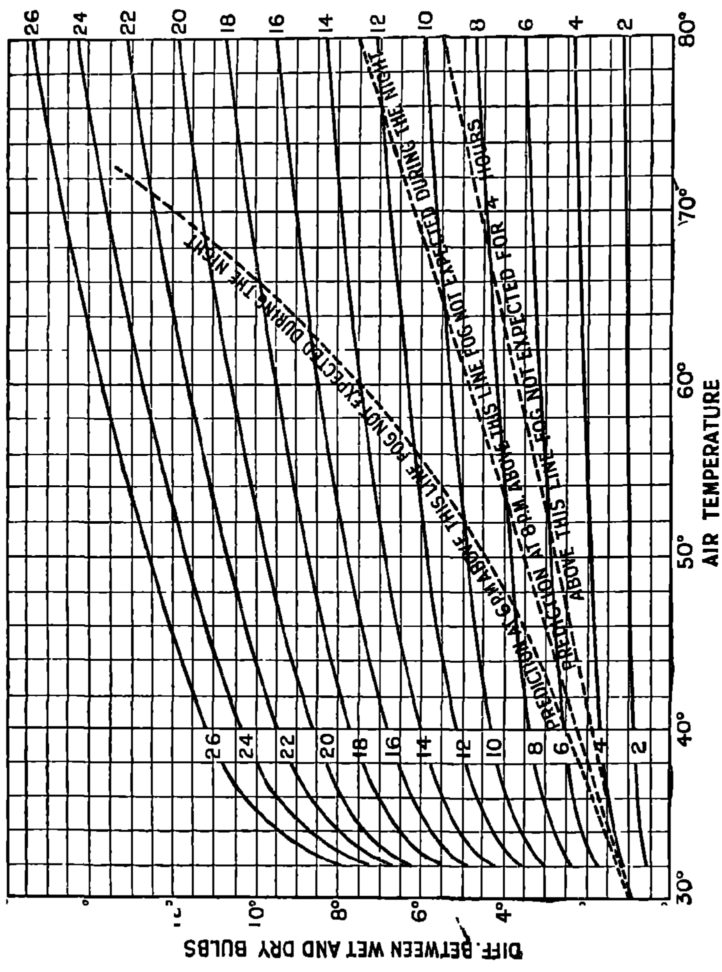


FIG. 174.—Diagram for Prediction of Fog. (G. I. Taylor.)

from the conditions when it is, comparatively speaking, probable. Lines are drawn for prediction at 6 p.m. and at 8 p.m. of fog during the night and at either time for fog within four hours.

From the point of view of forecasting weather an interesting feature of this process of anticipating fog is that it deals only with the physical measurements and makes no appeal to any knowledge of the general meteorological situation and the prospective changes therein during the night. We may note that the odds against a fog when conditions are represented by a point on the dry side of the curve are about ten to one, whereas on the other side of the line they are about even. Something interesting in the way of explanation of this unilateral behaviour would probably be disclosed by bringing into aid the results which can be furnished by the method of weather-maps with which this book is mainly concerned.

We have seen that for the formation of a fog, mixing is required, and that the necessary mixing can be secured by the eddy-motion due to air moving over the surface; but, for fog, it must not go faster (at the surface) than 5·5 miles per hour. The motion must be slow, but it must be there, otherwise there might be dew or even hoar-frost, but no fog because there is no mixing. So there is a lower limit of velocity as well as an upper limit, and this lower limit may be over-passed on a flat plain like the Old Deer Park, Richmond, where the Kew Observatory is placed. A surer locality for a process that must result in fog is a valley with sufficient slope on its sides and bottom to give, automatically, sufficient downward motion to the cooled air for the operation of mixing.

There are, moreover, the occasions when the meteorological situation might change at night after an observation at 8 p.m. in consequence of changes in the general environment. Some of these might certainly be foreseen, and it is to be hoped that some one who is curious about such things may find an opportunity to study the occasions when fog prediction fails; they are, from the point of view of forecasting weather, more interesting than the many occasions when it succeeds, as being the exceptions that test the rule. Not only are they interesting, but they are vitally important, for in the forecasting of fog meticulous accuracy is required.

CHAPTER XVIII

GALES AND GALE WARNINGS

GALES were the earliest care of the forecaster, on account of their importance for ships. According to the Beaufort scale of wind-force, which is given on pp. 20—21, winds which surpass the figure 7 are gales, storms or hurricanes. Gales claim careful attention from navigators, storms are more or less destructive of rigging and other property, and hurricane winds are defined as winds which no canvas can withstand; as a matter of fact, a real hurricane demolishes not only all exposed canvas at sea, but trees and buildings on land. As a result of the investigation of 1905 we now classify winds with velocity above 75 miles per hour as hurricane winds, those with velocity between 64 and 75 miles per hour as storm winds, and those between 39 and 63 as gales.

We do not have hurricanes in this country, but we do occasionally have winds of hurricane force, *i.e.*, with a velocity above 75 miles per hour. Here we are drawing a distinction between winds and gusts arising from the structure of natural air-currents, as shown by the tube-anemometers. The distinction will be evident from the comparison of the record of the cup-anemometer of Fig. 121A, or in the records of the observatories reproduced in the frontispiece, and that of a tube-anemometer in Fig. 117. The former gives the run of the wind in an hour; we call it the hourly wind, or the wind; the latter shows great fluctuations of velocity superposed upon the hourly wind and indicated by excursions of the pen through a considerable range. The extreme of one of these fluctuations is the velocity of a gust.

Also we sometimes have winds of storm-force though not very frequently. Although we have no hurricanes, and storm winds are rare, gales, regarded as including all winds exceeding force 7, are not infrequent, and have occurred often enough to be treated

statistically. They may, indeed, be regarded as the initiatory causes of the official weather-services of Western Europe.

FREQUENCY OF WINDS OF HURRICANE-FORCE, STORM-FORCE AND GALES IN THE BRITISH ISLES

By way of preface to the subject of this chapter some evidence of the frequency of the events under consideration is not out of place; we extract, therefore, from a work on "The Weather of the British Coasts," written for the Meteorological Office by the author at the request of the Admiralty in 1917, first a table of the number of winds of hurricane-force recorded as gusts on the tube-anemometers of the Meteorological Office since the beginning of this century; secondly, a table of winds of storm-force exceeding 64 miles per hour which have been recorded either upon the cup-anemometers or the tube-anemometers within the same period. The information has been amplified by that given in the Monthly Weather Report up to the end of 1921. We give, thirdly, a table of the odds against the occurrence of a gale on any day of the several months of the year, based upon the information about gales collected in the Meteorological Office in the past forty years, 1876 to 1915.

In the original specifications of the Beaufort scale a wind of force 7 was called a moderate gale. That is a curious name because the essential characteristic of a gale is its lack of moderation. It does not appear that seamen ever regarded a moderate gale as being more than "half a gale," and force 7 has never been classed as a gale in the registers of the Meteorological Office. We endeavoured to introduce the term "high-wind" in order to avoid the ambiguity. "Half a gale" would be equally effective for that purpose if seamen agree that "a moderate gale" is really "half a gale" and think "high wind" is not sufficiently nautical.

The records available for the compilation of the three tables which follow do not extend over the same period of years. The anemometers by which they were recorded have been erected at different times; the periods over which the several records extend are given approximately in years by the figures in the

summary of gusts of hurricane-force between 75 and 86 miles per hour.

TABLE OF GUSTS OF HURRICANE-FORCE ARRANGED IN ORDER OF VELOCITY.

Station.	Date.	Velocity of Hurricane Gust.	Average Wind Velocity in the Hour including the Gust.	Station.	Date.	Velocity of Hurricane Gust.	Average Wind Velocity in the Hour including the Gust.
		m.p.h.	m.p.h.			m.p.h.	m.p.h.
Quilty . .	27. 1.20	>112	52	Eskdalemuir .	25.10.17	90	57
Scilly .	8. 3.22	108	—	Pendennis Castle	3.12.14	89	63
Pendennis Castle	14. 3.05	103	—	Scilly . .	26.12.12	88	65
,, ,,	8. 3.22	103	76	Quilty . .	24.12.12	88	62
,, ,,	26.12.12	98	70	Southport .	4.12.14	88	62
,, ,,	4. 3.12	98	64	Roche's Point .	18.12.11	88	33
Scilly . .	16.12.17	96	65·5	Southport .	25.10.17	87	62
Plymouth .	8. 3.22	96	62	Pendennis Castle	18. 2.10	87	60
Holyhead .	2. 1.99	94	84	Scilly . .	4.12.14	87	46
Quilty . .	4.12.14	92	63	Southport .	7. 2.13	86	62
Pendennis Castle	27.10.16	91	60	,, .	2. 1.19	86	59
Southport .	12. 1.99	90	—	Holyhead .	4.12.14	86	56
Scilly .	23.10.09	90	70	,, .	16. 2.16	86	56
Southport .	14. 9.14	90	65	Quilty . .	7.10.18	86	49
Eskdalemuir	5.11.11	90	62	Pendennis Castle	12. 2.14	86	47
Scilly .	28.12.00	90	61				

Occasions of gusts above 75 miles per hour and less than 86 miles per hour are comparatively numerous; we need not specify each one of them, but record the frequency at the various anemometers :—

TABLE OF FREQUENCY OF GUSTS BETWEEN 75 AND 86 MILES PER HOUR.

Station.	Years of Observation.	Number of Gusts.	Station	Years of Observation.	Number of Gusts.	Station.	Years of Observation.	Number of Gusts.
Pendennis Castle	20	29	Aberdeen .	15	4	Gorleston .	14	2
Southport .	23	18	Plymouth	14	4	S. Shields .	13	2
Holyhead .	27	14	Rosyth .	11	4	Valencia .	5	2
Scilly . .	26	11	Edinburgh	7	3	Balmakewan	5	1
Quilty	11	7	Paisley .	8	3	Larkhill .	1	1
Roche's Point and Weaver Point	19	6	Dover .	11	2	Shoeburyness	20	1
Eskdalemuir .	12	5	Dwyran (Anglesey)	4	2	Spurn Head	5	1

TABLE OF WINDS OF STORM-FORCE 64 MILES PER HOUR, OR MORE, ARRANGED IN ORDER OF VELOCITY.

Station.	Date.	Velocity m.p.h.	Station.	Date.	Velocity m.p.h.
Holyhead . .	2. 1.99	84	Pendennis Castle	6. 1.06	65
Fleetwood .	12. 1.99	75	Scilly . .	26.12.12	65
Scilly . .	23.10.09	70	Southport .	14. 9.14	65
Pendennis Castle	26.12.12	70	Pendennis Castle	27. 1.17	65
Kingstown .	26. 2.03	66	Fleetwood .	25.10.17	65
Fleetwood .	3.12.09	66	" .	25.11.17	65
Pendennis Castle	26.11.12	66	" .	3.12.20	65
Scilly . .	16.12.17	66	Scilly . .	10. 9.03	64
" . .	12. 2.04	65	Pendennis Castle	6.12.11	64
			" "	4. 3.12	64

ODDS AGAINST THE OCCURRENCE OF A GALE ON ANY SECTION OF THE BRITISH AND IRISH COASTS on any day in the various months of the year.

Based upon records extending over the forty years 1876 to 1915. The figures represent in each case the "odds against one.")

Coasts.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
Scotland :—													
North-East .	5	6	7	15	27	74	102	43	17	8	5	5	10
East . . .	8	10	10	26	43	74	77	61	20	11	8	10	15
North-West . .	5	6	9	19	30	74	61	43	14	10	6	5	11
West . .	7	7	11	22	43	74	102	33	17	10	7	6	13
Ireland :—													
North-West . .	4	5	6	12	25	37	30	23	10	6	4	4	8
South-West . .	4	5	7	14	25	59	61	21	15	8	5	4	9
Irish Sea . .	5	6	9	15	39	42	43	23	14	8	5	5	9
St. George's Channel .	6	7	8	20	38	74	77	30	19	8	6	5	11
Bristol Channel . .	5	5	8	14	33	42	43	17	13	6	5	4	9
England :—													
South-West .	6	6	6	18	27	74	61	23	22	8	5	5	10
South .	8	8	12	26	51	99	51	21	24	9	7	6	13
South-East . .	9	11	11	32	61	149	77	30	29	10	7	7	16
East . . .	12	12	16	29	61	149	154	51	42	12	9	9	19
North-East . .	7	8	9	24	43	74	77	61	22	10	9	7	14

Ireland North-West stands out as the most stormy district, and England East as the most nearly free from such visitations.

The "favourite" day is January 28 in Ireland NW, the odds about which are just 21 : 19 against, or nearly even.

The "odds" are arrived at as follows : the average number of

gales within the month are first taken out: for example, out of forty 28th days of January 19 had gales and 21 had none, so the odds are 21 to 19 against having a gale on that day.

In Scotland North-East the average number of gales in January is five; the number of days without gale is therefore twenty six. The odds against a gale are 26 to 5, or 5 to 1.

GALE WARNINGS

When Admiral FitzRoy began the mapping of the weather in 1860 he soon turned his attention to precautions against destructive storms. In 1863 he established a system of warnings for gales with a supplementary signal for the probability of a storm, and from that day onward the warnings were called storm warnings. But in 1867 the special warning for storms was discontinued and the warning was intended only to indicate the probability of a gale with which a storm might, or might not, be associated. The name ought to have been changed to "gale warnings" at the same time, if misunderstanding were to be avoided. For that reason the terms "gale warning" and "gale signal" replace the older names "storm warning" and "storm signal," as the function and mode of operation of the service.

The warning for approaching gales or storms is a special branch of forecasting in which the forecaster has not only to anticipate the direction and force of the wind for the various localities within his area, but to send a notification to the gale signal stations on the coasts likely to be affected in case he is of opinion that gale force may be reached. The service has now been in operation for sixty years. It was introduced by the Board of Trade, on the initiative of Admiral FitzRoy, then in charge of the Meteorological Department, with a cone and drum as signals; the cone was to indicate the approach of bad weather for shipping, commencing with a gale or strong wind from the southward if the cone was shown point downward, or from the northward if the cone was shown point upward. The addition of the drum was meant to indicate the approach of the more severe gales, the

directions being indicated as before by the mode of displaying the cone. When the Meteorological Office was transferred from the Board of Trade to the supervision of the Royal Society in 1867, the issue of gale warnings was discontinued with the suspension of the issue of forecasts, but upon the representation by the Board of Trade that the service was regarded as being of material utility to mariners the issue of warnings was resumed as notified by Circular 717 of the Board of Trade, February, 1874. The use of the drum was, however, discarded, and no distinction is now drawn between the indication of gales and the severer forms of disturbance which may be called storms. Upon the renewal of the service the notice of an approaching gale was arranged to hold good for forty-eight hours from the time of issue, but, by a recent modification, the period has been restricted to the evening of the day following the day of issue, so that the duration of the warning is thirty-six hours for a notification based upon the morning chart, and twenty-four hours for one based upon the evening chart.

The regulations used to run as follows:—

STORM[1] SIGNAL SERVICE IN CONNECTION WITH THE METEOROLOGICAL OFFICE, LONDON

Explanation of Storm Signal Service

"The Meteorological Office issues notices by telegram of the probability of storms or strong winds on or near the coasts of the British Islands to ports and fishing stations recommended by responsible local authorities, and the fact that one of these notices has been received at any station is made known by hoisting a *Cone*, three feet high and three feet wide at base, and painted *Black* (Fig. 175).

"The *'South' Cone* (point downward) is hoisted for gales and strong winds

From south-east, veering to south-west, west or north-west;

,, south-west, veering to west or north-west;

[1] See p. 460.

From west, veering to north-west.
and also from east, veering to south or south-west.

DAY SIGNALS.

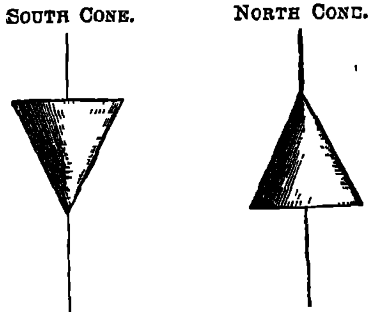


FIG 175.

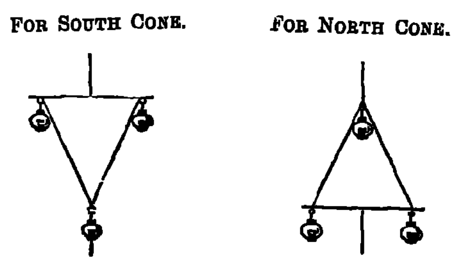
"The '*North*' *Cone* (point upward) is hoisted for gales and strong winds

From south-east, east or north-east, backing to north;
„ north-west, veering to north, north-east or east;
„ north, veering to north-east or east;
„ north-east, veering to east.

"At dusk, whenever a signal ought to be flying if it were daylight, a *Night Signal* consisting of three lanterns hung on a triangular frame (Fig. 176), may be hoisted in place of the

NIGHT SIGNALS

Lights in triangle (instead of the cone)



Three lanterns and one yard, 4 ft. long, will be sufficient.

FIG. 176.

Cone, point downward (for South Cone) or point upward (for North Cone), as the case may be. The lamps should be kept burning until, say, 9 or 10 o'clock.

"Gales sometimes follow one another in quick succession. An order to 'keep up' will be sent if the warning is to be continued beyond the ordinary limits; and an order to 'lower' will be sent if there is reason to believe that danger is over before the regular time has elapsed.

"If a gale has commenced before warnings are issued, notice to hoist the Cone will still be sent if it is expected that the gale will continue, or increase in force, but not otherwise.

Sudden Shifts of Wind

"A southerly gale often *veers* quickly to a point north of west, but a gale from the eastward is more likely to *back* to the *northward*.

"It is important to bear this in mind, especially in anchorages or harbours exposed to the northward.

Meaning of Signal

"The signal shows that an atmospheric disturbance is in existence which will *probably* cause a gale, from the quarter indicated, within a distance of (say) fifty miles of the place where the signal is hoisted. The signal station itself is sometimes comparatively sheltered. The meaning of the signal is simply, 'Look out! Bad weather of such and such a character is probably approaching you.'

"The warning is intended to continue from the time the telegram leaves the Meteorological Office until 8 o'clock on the evening of the following day.

"A warning message received after 9.30 a.m. would have been despatched the same day. The Cone should be hoisted immediately on receipt of the message *and kept flying until 8 p.m. on the following day,* but if it cannot be seen after dusk it may be lowered during darkness to save wear and tear.

"A message received before 9 a.m. would have been despatched on the previous evening, and have been delayed in transmission. In this case, on its receipt, the Cone should be hoisted at once, and kept flying till 8 o'clock in the evening, or till dusk if it cannot be seen after dark."

The Meteorological Office supplies the canvas cones, but not lanterns. In all cases the local authorities must undertake the charges incidental to the hoisting of the signal, such as flagstaff and gear, oil, etc., and also as to the keeping of the apparatus in repair, painting, etc.

There are 237 stations on the coasts or at ports of the United Kingdom for the display of warnings: 127 are in England and Wales, 71 in Scotland, 34 in Ireland, 3 in the Isle of Man and 2 in the Channel Islands. Hardly any are provided with the means for displaying signals at night.

The instructions of this circular, and the other particulars given, have now been modified. The number of stations is now set out as 185 in Great Britain. The meaning of the signal is that a gale is probable in exposed situations, or on the open sea within a distance of 50 to 100 miles of the station where the cone is hoisted. The gale anticipated will usually develop within twenty hours of the time of issuing the warning and frequently within ten hours. Occasionally, however, the gale develops more slowly than is expected and the period may be thirty hours; on the other hand, as the warnings take some time in transmission, the gale may have commenced before the warning has arrived. The cone is then hoisted on receipt of the message.

The cone remains hoisted after receipt of the warning-message until instructions are given for it to be lowered. But in special cases the times at which the signals are to be lowered are stated in the first warning telegram. Normally, the order to lower the cone will be sent when the gale has passed, and a period of twenty-four hours or more free from gales and high winds is anticipated. An order to "keep cone flying" may be sent on some occasions when the cones are still flying if there has been a temporary abatement of wind and a renewal of the gale is definitely foreseen.

A proposition was before the International Meteorological Committee, on the recommendation of a Commission appointed in 1907, to consider the question of introducing an international system of storm signals and to adopt the following scheme of signals :—

PROPOSED INTERNATIONAL STORM SIGNALS.

Day.	Night.	Description of Gale.	Day Signals.	Night Signals.
△	W R R	For a gale commencing with wind in the north-west quadrant.	Single cone, point upward.	Three lanterns in vertical line, one white above two red.
▽	R R W	For a gale commencing with wind in the south-west quadrant.	Single cone, point downward.	One white below two red.
△ △	W W R	For a gale commencing with wind in the north-east quadrant.	Two cones, one above the other, both point upward.	One red below two white.
▽ ▽	R W W	For a gale commencing with wind in the south-east quadrant.	Two cones, one above the other, both point downward.	One red above two white.
△ ▽	W R W	For a hurricane.	Two cones, with their bases together.	One red between two white.

The scheme of day signals was approved by the International Meteorological Committee at Berlin in September, 1910, and has already been adopted in the United States and in France. The scheme of night signals has been proposed in lieu of the original scheme of the Commission to which objection was taken on the ground that the signals might

be confused with port signals. The final decision in respect of this question is not yet reached.

The gale warning service is attended with considerable difficulties, some of a meteorological character, others arising from the incidental conditions under which the work is carried on. Of the latter the chief difficulty is that arising from the closing of telegraphic communication with the signal stations at 8 p.m. on week-days and the very limited office hours on Sundays at the post-offices in the rural districts where most of the signal stations are situated. These circumstances, combined with the fact that so few signal stations have the lanterns for exhibiting the signals at night, practically limit the service to daylight hours on week-days, and in the winter, when storms are frequent and daylight scanty, the conditions are felt as very depressing to the service, because our outlook for a forecast of such precision as is required for distinguishing between a gale and no gale is limited in reality to less than twenty-four hours. Frequently there are only few hours between the issue of the warning and the incidence of the gale. A warning sent out in the evening may, in consequence, result in the hoisting of a cone on the following morning, and the gale may have passed in the night. Thus, all the operations of the service may have been carried out in strict conformity with the rules and with the clearest anticipation of the meteorological conditions, and yet result in the rather ridiculous manœuvre of hoisting a signal cone for a gale that is already over.

There is a prospect of these difficulties disappearing with the spread of facilities for receiving messages broadcasted by radio-telegraphy.

METEOROLOGICAL DIFFICULTIES IN CONNECTION WITH GALE WARNINGS

It would perhaps be easy to modify the rules in such a way as to enable the local official in charge of the cone to save the situation by not hoisting the cone when he thinks all

danger is past, if it were not for the meteorological difficulties of the situation. These are of varied character. The first is the difficulty of knowing what the real or effective force of the wind is from observations in a particular locality. So much depends upon the exposure, that the local observation is insufficient as a general indication for the region. This point is very clearly brought out in the figures, for the year, for the various anemograph stations in connection with the Meteorological Office. I quote for the year 1909 from the "British Meteorological Year Book," Appendix III.

TABLE OF THE NUMBER OF HOURS OF WIND OF GALE FORCE AT ANEMOGRAPH STATIONS IN CONNECTION WITH THE METEOROLOGICAL OFFICE IN 1909.

	Number of Hours of Beaufort Numbers.						Number of Hours of Beaufort Numbers.				
	8	9	10	11	12		8	9	10	11	12
Valencia	7	—	—	—	—	Deerness	55	1	—	—	—
Roches Point	63	8	—	—	—	Aberdeen	6	—	—	—	—
Scilly	118	27	5	1	—	North Shields	5	—	—	—	—
Falmouth	—	—	—	—		Yarmouth	21	—	—	—	—
Pendennis	196	42	9	—		Gorleston	15	1	—	—	—
Plymouth	10	—	—	—	—	Shoeburyness	4	—	—	—	—
Glasgow	—	—	—	—	—	Dover	13	—	—	—	—
Fleetwood	88	24	2	2	—	Armagh	—	—	—	—	—
Southport	65	3	2	—	—	Alnwick Castle	—	—	—	—	—
Holyhead	54	7			—	Stonyhurst	—	—	—	—	—
Kingstown	57	—	—	—	—	Pyrton Hill	2	—	—	—	—
Dublin	—	—	—	—	—	Kew	—	—	—	—	—
Brighton	1	—	—	—	—						

It will be seen that the incidence of gales is not at all so uniform as might be expected, and that at seven stations, although care is always taken to get a free exposure for the anemometer, no gales were actually recorded within the year. I have added to the table given in the Year Book the number of gales during the same year as estimated at various coast stations, taken from the annual summary of the Monthly Weather Report.

TABLE OF THE NUMBER OF GALES REPORTED FROM STATIONS ON THE COASTS IN 1909

Castlebay, Hebrides	8	North Shields	6	Portland Bill	21
Sumburgh Head	9	Spurn Head	17	Malin Head	28
Stornoway	37	Yarmouth	9	Blacksod Point	15
Deerness	16	Clacton-on-Sea	5	Donaghadee	3
Wick	15	Dungeness	10	Valencia	4
Nairn	1	Liverpool	1	Roches Point	19
Aberdeen	1	Holyhead	21	Scilly	6
Leith	1	Pembroke	16	Jersey	14

This point is further illustrated by a diagram published in the report of the Meteorological Council for 1905, p. 61

PERCENTAGE OF GALE WARNINGS JUSTIFIED BY SUBSEQUENT STRONG GALES IN 1895–1904 and 1904

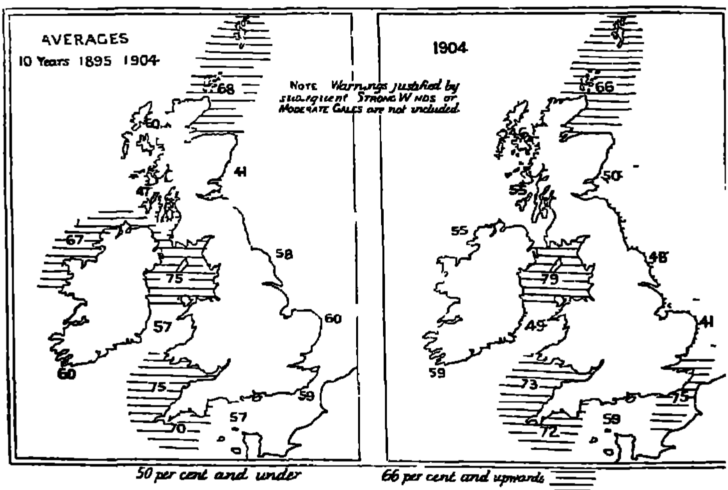


FIG 177

(Fig 177), showing the percentages of gale warnings justified by subsequent strong gales in the ten years, 1895—1904, and in the single year 1904. There are certain parts of our coasts and the adjacent seas which were exceptionally free from the gales for which warnings were issued. These local peculiarities have probably more to do with the local facilities of observation than with the meteorological conditions as expressed by isobars

SECONDARIES

Another interesting point in connection with the gale-warning service is the manner in which the distribution, over a district, of winds of gale force is affected by secondaries. If we may suppose, to begin with, a cyclonic depression with gradient uniform over the southern side of the depression and approximating to gale force, we may add as a superposed distribution of pressure, possibly transmitted from the higher regions of the atmosphere, a small circular depression with its centre south of that of the main system. The result will evidently be to diminish the gradient in the northern part of the area of the superposed depression, because the gradients of the two components are opposed there, and to increase the gradient in the southern portion by an equal amount, because the two gradients are there concurrent. Such an analysis applies to the case of March 24, 1895, represented in Fig. 38, Chap. V., and there are all degrees of intensity of effect corresponding with such a superposition. The result as regards gale warnings may be that in the northern part of the locality of the secondary the warning cone may hang in air which is nearly calm, while another in another part of the same district may be blown away by the exceptional severity of the gale that was anticipated for both stations alike.

The process of gale warning is in every way similar to that of forecasting, with the addition of the keeping of a look-out for the strengthening of winds in consequence of modifications in the distribution of pressure which are important in this respect, but insignificant from any other aspect. An easterly wind over the east and south of England has a way of developing into a gale in a manner which is surprising to those who are not watching the pressure movements with the necessary closeness. For southerly and westerly gales we are accustomed to watch the arrival of depressions from the Atlantic which develop steep gradients, and the secondaries which exaggerate the gradients in certain parts. Northerly

and easterly gales are sometimes incidental to the passage eastward of cyclonic depressions with centres which pass up the Channel, and as these are often accompanied by snow, they are apt to be labelled with the name of blizzard, as were the easterly gales of January 18, 1881, and March 9 and 10, 1891.

"GALES MISSED"

In gale warning, the "missing" of a gale, that is, the omission to issue warnings before the gale is actually shown on the charts, is regarded as being a more serious matter than the issue of a warning which may result only in a strong wind, or in no increase of wind at all. It has always been supposed that the facilities for identifying the approach of a depression carrying winds of gale force would be so much facilitated by reports by radio-telegraphy from the Atlantic, that when these were once received, the avoidance of "missed" gales would be an easy matter. This view is doubtless based upon the assumption that gale-carrying depressions pass across from the western region of the Atlantic, the neighbourhood of the transition from warm to cold water, almost with the regularity of an ocean steamer. For that, as for so many other general views of meteorological conditions, some striking instances can be adduced, but it is, unfortunately, not generally true. Since January, 1909, when the transmission of wireless messages from liners began, we have enlarged our experience of the relations of the off-shore to the on-shore conditions, and we find that we have still to watch with the same care, and with hardly less anxiety, the course of events off our western shores. The first set of seven daily synchronous charts of the Atlantic (April 7—13), based upon the combination of the wireless messages from the Atlantic with the telegraphic reports from the Continent and Atlantic Islands, which was published on the Monthly Meteorological Chart of the Atlantic and Mediterranean for May, 1910, showed an interesting case of a deep depression apparently stationary in the middle of the

Atlantic for nearly a week, while a high pressure area circumnavigated our islands. We find the same facility for the changing of a light southerly current into a southerly or westerly gale in the neighbourhood of the West of Ireland, as we find for the transmutation of an easterly air into an easterly gale on our southern coasts. But with the additions to our stock of data that radio-telegraphy has given us, we approach the study of the subject with more knowledge and a far greater grasp of the actual facts. Ultimately we may hope to be able to discontinue the class of "missed" warnings: in the meantime let me give the official list of warnings missed in the year 1908:—

GALES EXPERIENCED IN 1908 FOR WHICH NO WARNINGS WERE ISSUED

(From the Report of the Meteorological Committee for the year ended March 31, 1909.)

February 21. *A strong gale from W. and N.W. in Scotland E.* Caused by a large depression which spread southwards from Iceland. Our extreme north-west coasts were warned on the evening of the 21st; the gale extended further eastward than was expected.

February 24. *A fresh to strong gale from N.W. in the Bristol Channel, and in England S.W and S.* Warnings were issued to most of our western coasts on the evening of February 23, owing to the appearance of a deep depression between the Faröe Islands and the Norwegian coasts. By next morning the gale had extended also to the English and Bristol Channels; it was then too late to warn.

April 3. *The strong S.W. to N.W. winds* which prevailed at this time on our W. and N. coasts reached the force of a gale in the north of Ireland and the Irish Sea. The gale was sporadic, and was scarcely felt at any land station.

August 23. *A fresh S.W to W. gale in the English Channel.* Due to a complex depression of no great intensity which appeared over the northern parts of the Kingdom. The

conditions at 7 a.m. on the 23rd did not appear sufficiently threatening to justify the issue of warnings. The 23rd was a Sunday, and it was therefore impossible to take any subsequent action until the evening, when the gale was already blowing.

August 27. *A strong S.W. gale in the Southern part of England E.*—All our western and southern coasts were warned on the afternoon or evening of the 26th. It was not anticipated that the gale would extend to any other part of our coasts.

October 19—21. *A S. to S.E. gale in the North-east of Scotland.*—A large anticyclone lay at this time over Northern Europe, and the gale was the effect of a steep gradient due to the proximity of the low pressure system off our western coasts. The exposed parts of the coast were alone affected.

November 13—14. *A gale from various quarters on our Western Coasts.*—Caused by a small depression which appeared off the south-west of Ireland on the evening of the 13th and afterwards travelled over the United Kingdom in an easterly and south-easterly direction. The gale was felt at less than half the stations in the various districts affected, but was locally rather severe.

November 19. *A fresh N.W. gale in the Bristol Channel and the Irish Sea.* At 6 p.m. on the 18th the appearance did not seem very threatening; by next morning the gale, which was of a sporadic nature, was already blowing.

December 7—8. *A fresh S.W. gale on the more exposed parts of our Western and Northern Coasts.*—Caused by a large depression which extended southwards from Iceland. Strong winds were anticipated, but in several localities represented by lighthouses and light vessels the wind is reported to have reached the force of a gale.

December 23—24. *A S.E. gale in the South of Ireland.*—Caused by a small depression which skirted our extreme south-west coasts. The indications afforded by the observations at shore stations were not very threatening, and it was

only on outlying parts of the coasts that the gale was at all severe.

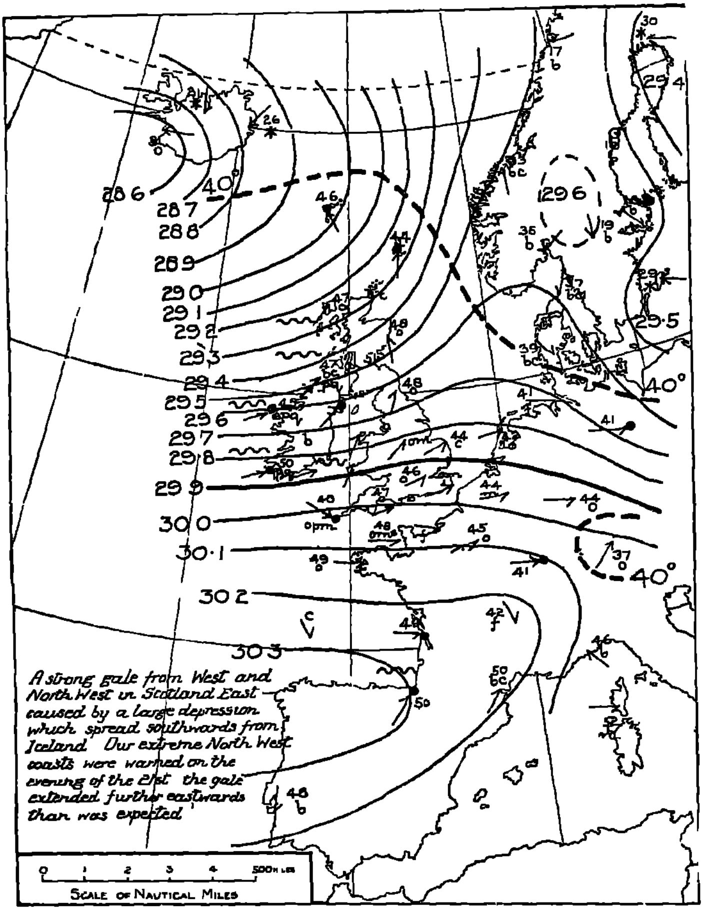
We give two charts by way of illustrating the meteorological circumstances attending the missing of warnings. Figs. 178 and 179 are the charts for February 21 and 22, 1908, and refer to the first of the occasions of a "missed gale" in that year. It will be seen that the difference between what was anticipated and what transpired is not very large. Most of the other cases are of a similar character, but there are occasions on which anticipation is in error on account of an entirely unsuspected change of type, as in the example of February 20, 21, 1893, dealt with by M. Guilbert and represented in Figs. 183A, 183B.

The reader who is interested in questions concerning gales and their incidence on the coasts of the British Isles should consult the paper on the subject by Mr. F. J. Brodie, of the Meteorological Office, published in the "Quarterly Journal of the Royal Meteorological Society," vol. 28, pp. 121–157. Besides statistics of the local and seasonal distribution of gales, he will find charts of the most notable gales of the thirty years, 1871–1900. Since the publication of that paper Mr. Brodie has completed the statistics of gales in the various districts of the British Isles for the Meteorological Office.

WARNINGS DISREGARDED

Side by side with the subject of the warnings missed by the forecasters there ought to be a section on warnings which have been issued from the Office and have been disregarded by those for whose protection they were intended. It is not often that information of that kind comes to hand in such a way as to point a moral, but during the war when navigation along the east coast was peculiarly difficult, an obvious example occurred. At 3 p.m. on October 30, 1914, the Office issued a warning of a northerly gale on the north-east coast; at 4 p.m. H.M. Hospital Ship *Rohilla* left the protected harbour of Leith and proceeded along the coast southwards. She was driven ashore at Whitby by the force

1908. February 21, 8 a.m.



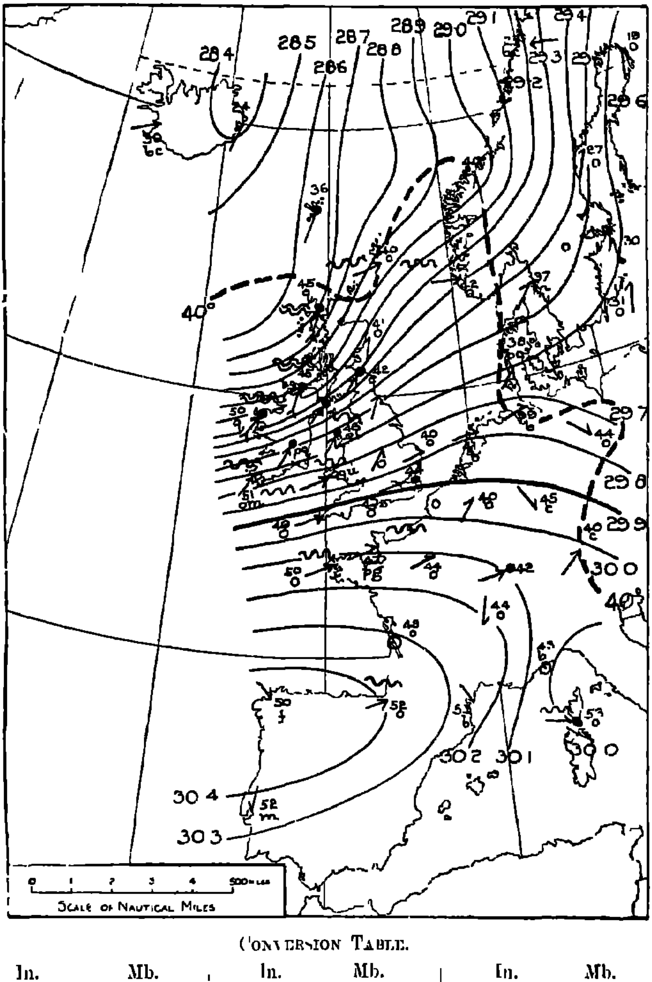
CONVERSION TABLE.

In	Mb.	In.	Mb.	In.	Mb.
28·6	968·5	29·2	988·8	29·8	1009·1
28 7	971·9	29·3	992·2	29·9	1012·5
28 8	975·3	29 4	995·6	30·0	1015·9
28 9	978·6	29·5	999·0	30 1	1019·3
29 0	982·0	29·6	1002·4	30·2	1022 7
29·1	985·4	29 7	1005·7	30·3	1026·1

The bold dotted line is the isotherm for 40° F., 277 4 t.

FIG. 178.—Chart for the Day Previous to the "Missed Gale" of February 22, 1908.

1908. February 22, 8 a.m.



Conversion Table.

In.	Mb.	In.	Mb.	In.	Mb.
28·4	961·7	29·1	985·4	29·8	1009·1
28·5	965·1	29·2	988·8	29·9	1012·5
28·6	968·5	29·3	992·2	30·0	1015·9
28·7	971·9	29·4	995·6	30·1	1019·3
28·8	975·3	29·5	999·0	30·2	1022·7
28·9	978·6	29·6	1002·4	30·3	1026·1
29·0	982 0	29·7	1005·7	30·4	1029·4

The bold dotted line is the isotherm for 40° F., 277·4 t.

Fig. 179.—A "Missed Gale."

1914. October 30, 7 a.m.

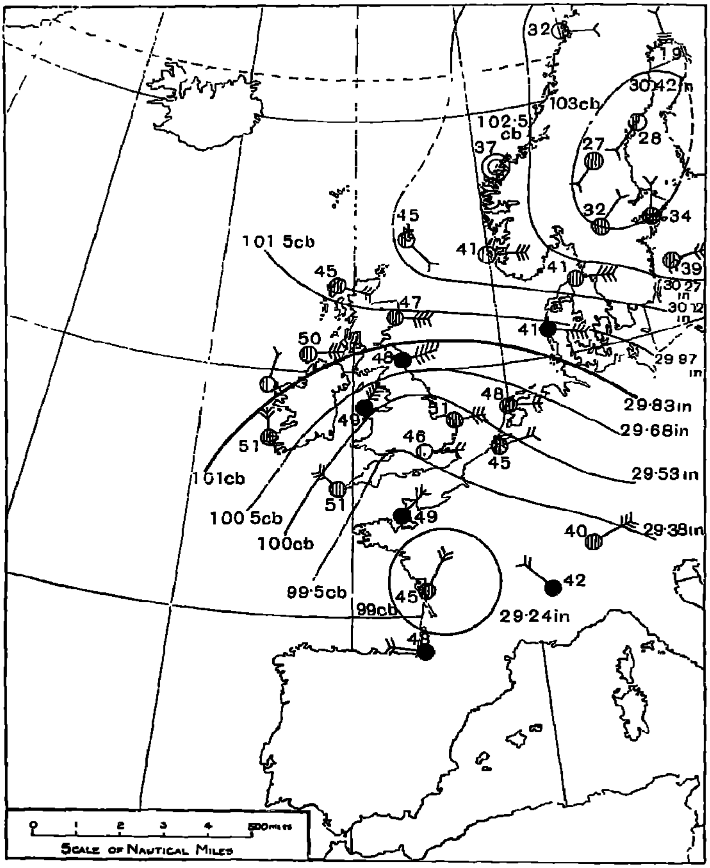


Fig. 180.—Chart for the Morning of the Wreck of the *Rohilla*.

of the gale with a total loss that the work of the Meteorological Office was intended to avoid.[1] The meteorological situation which caused the wreck is represented in Fig. 180.

Such *contretemps* as these are easily avoidable now because the necessary information can be received on ships themselves by radio-telegraphy.

WEATHER CHARTS ON SHIPS

This constitutes a development of the practice of using telegraphic reports for the construction of weather maps which promises to be of great utility for ships at sea. The ship itself, by wireless telegraphy, can collect reports from other ships and from distributing stations on shore which are within range. The messages transmitted from ships in accordance with an international plan for the amplification of the charts of the central offices are equally available for other ships within range, and the messages which are " broadcasted " from the shore stations can also be received. A wireless operator on board ship has, therefore, from time to time information in his possession out of which a useful weather map can be constructed. This is especially the case when the ship is not far from the broadcasting stations on shore. The information so obtained, in the hands of ships' officers with a sufficient knowledge of the method of forecasting by weather charts, should prove of direct utility in making a landfall, an occasion for which a knowledge of coming weather is peculiarly useful.

The line of procedure in order to secure the advantage of this development is indicated in a small *brochure* by Commander L. A. Brooke Smith, Marine Superintendent of the Meteorological Office, entitled " Weather Forecasting in the Eastern North Atlantic and Home Waters for Seamen."[2]

[1] " Report of the Meteorological Committee, 1914–1915, p. 37.
[2] M.O. Publication 246, 1921.

CHAPTER XIX

FORECASTS FOR AGRICULTURISTS

NIGHT FROSTS IN SPRING

The frosts which occur in spring are specially destructive on account of the sensitiveness of young plants, and it is, therefore, desirable to recognise the conditions under which they are likely to occur and, if possible, to take precautions for the protection of young growth.

CHANGEABLENESS OF SPRING WEATHER

As measured by instruments the weather is not much more changeable during spring than it is in winter or summer, but the changes are of greater practical importance. The change of shade temperature, for example, from 45° to 25° in spring is much more destructive than a change from 35° to 15° in winter or from 80° to 60° in summer.

The following examples taken from the Weekly Weather Report show how the range of temperature during conspicuously sunny weeks varies at different times of the year. The figures refer to the district included in the Report under the name "Midland Counties."

Time of Year.	Mean Maximum Temperature.	Mean Minimum Temperature.	Mean range.
	F.	F.	F.
Winter, week ended February 28, 1891	54·3°	26·1°	28·2°
Spring, week ended April 10, 1908 .	62·2°	31·9°	30·3°
Summer, week ended August 26, 1899	80·6°	51·9°	28 7°

A diagram of the incidence of frosts, in the thermometer screen and on the ground, at Kew Observatory in the years 1871 to 1918 inclusive, prepared in the Meteorological Office for exhibition at a Royal Agricultural Show indicates that screen frosts have occurred

up to May 5, and have begun again as early as October 4. Ground frosts have occurred up to June 25 and have begun again as early as August 15. The latter event was quite exceptional, in 1887. Such data are to be regarded as concerning only the immediate locality; different results would be obtained from any other site.

CAUSES OF DESTRUCTIVE FROSTS IN SPRING

Destructive frosts in spring may arise from three separate causes, and on occasions two of these causes may combine.

COLD SPELLS IN SPRING

The first of the three causes here referred to is the occurrence of an ordinary type of cold, wintry weather which is not uncommon in spring. The barometer falls, with a northerly, north-easterly or easterly wind; we get, in consequence, a cold spell, probably with snow.

VEERING WIND, WITH RISING BAROMETER

The second of the three causes is to be noticed in changeable April weather, and can be referred to the passage of barometric depressions. If the barometer and wind are watched it will be noticed that after rain with a falling barometer and a southerly or south-westerly wind, the wind veers to the west, north-west, or north, and becomes appreciably drier, and the weather clears and becomes cold. If this change happens towards the evening, and the wind drops when the sky clears, a frosty night is almost certain.

COLD NIGHTS AFTER WARM DAYS

The third recognised cause refers especially to night frosts which may occur with destructive effect if the night is clear, even after a warm, sunny day, and the destruction is the more complete if the day which follows the cold night is itself sunny and warm. The most destructive frosts occur when the causes here noted as the second and third combine, when cold, clear

weather with a calm night comes at the close of a boisterous day, with a veering of the wind to the north-west or north.

FROSTS ON CALM NIGHTS

We may consider a little more in detail the process by which the cooling takes place on calm clear nights. Over our Midland Counties in April there is on the average a difference of 16·3° F. between the highest temperature of the day and the lowest temperature of the night. In May the average difference amounts to 17·7° F. During clear weather the day temperature is increased by the warm sunshine, but the night temperature is lowered. After the sun is gone, when the earth and its covering herbage are exposed to a clear sky, they lose heat and get colder than the air. They may cover themselves with dew or hoar frost which are sure signs of their having been cold. But in turn they cool the air next to them, and the cooled air in its turn trickles like water downhill to the valleys.

THE EFFECT OF SITUATION

In these circumstances the plants on the tops of the hills are fortunate, for the air which replaces that which has been cooled and trickled away is practically part of the original undisturbed supply and is comparatively warm. The plants on the hillside get the air which trickles down from above, and is consequently colder than that enjoyed by the plants at the top. The cooling goes on as the air flows down the valleys. But the worst fate awaits the plants in the valleys where pools of cold air form. Thither the coldest air gravitates, and for the plants at the bottom the air is stagnant; consequently they may cool by exposure to the open sky much in the opposite way to that in which a joint roasts in a "hastener" before a fire. The shape of the ground which causes a pool of stagnant air to form takes the part of the "hastener."

TEMPERATURES ON THE GRASS AND IN THE SCREEN

The effects of this process of cooling may be very different in situations which are quite near to one another. Meteorolo-

gists are accustomed to note such effects by having one thermometer "on the grass," supported on a couple of forked twigs close to the ground, and another "in the screen," which means that it is kept in a louvred box at a height of 4 feet from the ground. On calm, clear nights the effect of the protection of the screen is very striking. The differences are not altogether due to enclosure in a screen; the height of the screen above the ground has something to do with it because the trickling stream of cold air keeps to the ground, and often is not very thick.

The following examples for the night of April 7—8, 1908, show how very variable is the amount by which the temperature on the grass may fall below that in the screen :—

Station.	Minimum in Screen.	Minimum on Grass.	Difference.
Harrogate	36°	26°	10°
Huddersfield	31°	26°	5°
Buxton	26°	20°	6°
Nottingham	30°	23°	7°
Birmingham	36°	16°	20°
Oxford	30°	22°	8°
Cirencester	31°	28°	3°
Marlborough	25°	16°	9°
Cambridge	28°	26°	2°
Llangammarch Wells	23°	10°	13°

DISTRIBUTION OF TEMPERATURE DURING NIGHT FROSTS

The following conclusions regarding temperature during frosts on calm nights are well established :—

(a) The frost becomes more severe as one goes from the hills down to the valleys, and hollows on the hill-sides are colder than the more exposed parts.

(b) The frost is most severe at the ground and becomes less severe at shrub height, still less so at tree height, so that herbage and low shrubs may be destroyed when higher shrubs and trees are spared.

(c) An overcast sky or a light wind generally prevents ground frosts.

These facts are now common knowledge among meteorologists. They lend themselves easily to verification by any one who possesses a pair of self-recording thermographs, which are now obtainable from the instrument-makers at a very moderate cost. The late Mr. E. A. Lee obtained some very interesting records with three such instruments exposed in his orchard, on the ground, in the screen at 4 feet and on a post 10 feet high. The relative coldness of the ground on cold nights is very noticeable. Corresponding records have been obtained by Mr. C. J. P. Cave at Stoner Hill, near Petersfield.

The difference between hill-top and valley has been effectively recorded in the Esk valley near Eskdalemuir as compared with a hill-top overlooking the dale. Similar observations have been made and described by Professor McAdie of the Aerological Observatory of Harvard College, Blue Hill, Mass. An account will be found in the chapter on Frosts in the work on Aerogaphy by that author, pp. 259—272.

It is also a well-established meteorological fact that, on the average, wind falls off in the evening, and in settled weather a calm night often follows a day with a good breeze. This is especially the case at Richmond, Surrey, with a westerly wind (see p. 253 and Frontispiece).

FORECASTS OF SPRING FROSTS AND NIGHT FROSTS

Referring to the three causes already described, the first two are easily associated with general meteorological conditions over the country, and to anticipate them forms part of the ordinary duty of weather forecasting. The changes are often very sudden, and while it is as a rule possible to anticipate their general character, it is less easy to form an estimate of the intensity of the changes. The difference between the changes which produce only a chill and those which cause a frost is not indicated on the maps used for forecasting.

FORECASTS OF FROSTS ON CALM NIGHTS

The frosts of calm nights are still more difficult to deal with by forecasts issued from a central office. They are subject to the effects of local peculiarities of site, and circumstances of which account can only be taken by those who are on the spot. A light air, hardly strong enough to be called a wind, will keep away a night frost by preventing stagnation; a calm on the other hand favours frost, but from the point of view of the weather-forecaster the calm may be an artificial calm due to surrounding trees or buildings, and not at all due to what he would understand by the weather.

It has already been pointed out that situation, whether on a hill, or hillside, or a valley, is also of importance. It is, therefore, necessary that persons interested in protecting their crops from frost should make use of their local knowledge in extension of the information to be obtained from forecasts.

WEATHER MAPS

One of the best aids to the use of local knowledge is the regular study of weather maps. The Meteorological Office issues daily charts of the weather over the British Isles and north-western Europe, which can be had by anyone on payment of the cost of postage and covers (see Fig. 6). The conditions for the occurrence of frosts can be watched much more effectively by an examination of the daily map than by the mere consultation of the forecast which is drawn up for a whole district and must be limited to about a dozen words.

OTHER AIDS TO ANTICIPATING NIGHT FROSTS—DEW POINT

Further information about the probability of a night frost may be got from local observations of the temperature and humidity of the air, obtained from the dry and wet bulb thermometers. From these readings on any occasion the

so-called "dew point" of the air can be computed. The dew point is the temperature at which dew begins to form.

It has been supposed that on a calm night the air cannot be cooled far below the temperature of the dew point of the previous evening, but that this is not the case is shown in five examples in the following table:—

Date.	Maximum during day	At 9 p.m.			Minimum during following night.	
		Dry bulb.	Wet bulb.	Dew point.	In screen.	On the grass
1. Cambridge, June 5, 1906	57·3°	46·0°	43·8°	41·3°	32·5°	28·1°
2. Cambridge, June 6, 1906	62·3	50·2°	48·0°	45·7°	34·2°	29·0°
3. Cambridge. June 7, 1906	68·2°	51·9°	45·1°	39·2°	33·6°	29·0°
4. Garforth, June 5, 1906 .	60·0	50·0°	46·0°	41·8	30·0°	20·0°
5. Cambridge, April 16, 1906	59·9	41·5°	35·2°	27·4°	27·0°	25·2°
6. Cambridge, April 17, 1906	63·2°	41·8°	40·3°	38·4°	30·6°	30·0°

All we can say is that the loss of heat is checked when the temperature falls to that of the dew point. Three causes combine to bring about this result: (a) While the temperature is above the dew point evaporation is proceeding from the ground and from herbage, and causes a loss of heat from them in addition to that due to exposure. Below the dew point this additional loss of heat does not occur: (b) If exposed surfaces are cooled below the dew point, moisture condenses on them in the form of dew (or hoar frost), and in the process a certain amount of heat is liberated from the condensed moisture which in part balances the loss of heat due to exposure: (c) The cooling of the air may result in the formation of mist which, acting as a screen, checks a further fall of temperature. Examples (5) and (6) in the preceding table illustrate the influence of varying conditions of humidity. The dry bulb temperatures at 9 p.m. were

practically identical on the two days, but whereas on April 16 the dew point at that hour was 27·4°, on April 17 it was 38·4°. On the former day a frost was highly probable, and the inference would have been justified as the temperature fell to 27·0° and 25·2° in the screen and on the grass respectively. On April 17, with a dew point as high as 38·4°, there was less likelihood of frost, and, as a matter of fact, the lowest readings were 30·6° and 30·0° respectively. Destructive frosts on calm nights are thus more likely when the air is dry, that is when the dew point is far below the air temperature, or the wet bulb is far below the dry, than on nights when the air is moist or the dew point and wet bulb temperatures are near the dry.

PRACTICAL HINTS

From what has been said above it will be gathered that anyone who is interested in protecting his crops from night frosts and, therefore, wishes to know beforehand when frosts are likely to occur, will do well to study:—

(1) The peculiarities of his locality, to know whether from being in a hollow or valley it is specially liable to frosts on calm nights.

(2) The daily charts, with or without forecasts by telegraph, in order that he may recognise the meteorological conditions in which the weather is likely to become cold and calm.

(3) The readings of the dry and wet bulb thermometers, so that he may recognise the occasions when ground night frosts are likely to be severe on account of the dryness of the air. For additional note see p. 487.

PROTECTION AGAINST EXPECTED FROSTS

The best method of protection for young plants against night frosts is to cover them up and thereby prevent, first of all, the loss of heat, and, secondly, the access of cold air.

Other means of protection have been tried. Saturation with

water of the ground in which the plants are growing is resorted to in fruit plantations in California. Possibly the evaporation of the water is in itself a protection, as it promotes the formation of a mist over the land to be protected, but the warmth of the water itself no doubt also acts to prevent the air just above it being cooled as much as it would have been if the ground had been dry. On the other hand, Continental writers point out that delicate plants are more sensitive to the effects of frost when their cells are fully charged with water than when they are in a dry condition, and then the adoption of this method, though mitigating the intensity of frost, may lead to increased damage to the crop. "Smudging," *i.e.*, covering the area with smoke from the combustion of damp straw or other smoky fuels, has been recommended as a protective measure, and the experiments have given rise to some discussion. Possibly differences in the character of the crops to be protected, more particularly the heights of the sensitive parts above the ground, may account for the apparent difference of opinion. On occasions when there is an appreciable breeze, saturation of the ground is probably harmful, as it would promote increased evaporation and so lead to cooling, while the protecting mist would be dispersed by the breeze as rapidly as it was formed.

It used to be supposed that vegetation suffered especially when the plants were rapidly warmed by the sun after being exposed to frost, so that protection was regarded as necessary in the early morning when the sun is rising in order to prevent too rapid thawing of the plant cells.

In a paper in the "New Phytologist," by Professor F. F. Blackman, on "Frost and Vegetation," it is pointed out that injury to plants by spring frosts is due to the absence of protective sugar in the tissues of the plants. Plants which can weather a winter develop sugar during cold, but a few days of warm spring weather cause the sugar to be reconverted into starch, and render the plant defenceless against a frost.

ADDITIONAL NOTE

The question of ground-frosts has been treated in two papers, by Captain T. Bedford Franklin[1] in which the author draws attention to the importance of the temperature of the ground, especially when it is not itself frozen, in controlling the temperature of the lowest layers of the air over ground which is not covered with herbage. He notes that the minimum temperature on the grass is not a proper criterion of the temperature of the air over soil because the grass forms a non-conducting layer which prevents the warmth of the ground from exercising fully its power of compensating loss by radiation from the surface. In the second paper he gives a formula for forecasting, from observations at 6 p.m., the minimum temperature of the surface layer of open soil on calm clear nights, which has given results in remarkable accord with the observed surface-temperatures, so that the occurrence of ground-frost can be forecasted with a remarkable degree of exactitude, although the intensity of the frost, when it does occur, is not fully indicated. For the particulars the reader must be referred to the original papers.

FURTHER INFORMATION FOR AGRICULTURISTS

These notes were drawn up as a leaflet for the information of those who are interested in the protection of young crops from injury by night frosts. There are other sides of meteorological work which are related to agriculture, such as the special forecasts of weather during the hay and corn harvests and the notifications of spells of weather which are referred to on p. 552. The use of the experiences of weather for forecasting the yield of crops is another separate field; of that Mr. R. H. Hooker is the chief exponent.

[1] "Proceedings Roy. Soc. Edin.," vol. 39, p. 120, and vol 40, p. 10, 1919. Formulæ connecting dew-point and subsequent minimum temperature are also given in "Meteorological Magazine," April, 1923.

CHAPTER XX

COLLIERY WARNINGS

THE relation of explosions in coal mines to the conditions of weather has formed the subject of a voluminous correspondence and of communications to various scientific and technical societies. As long ago as 1874 an endeavour was made to associate colliery explosions with the rapid falls of pressure which are incidental to the advance of deep cyclonic depressions. Mr. R. H. Scott, of the Meteorological Office, and Mr. W. Galloway, one of H.M. Inspectors of Mines, dealt with the matter in a paper published in the "Proceedings of the Royal Society."

The subject came up for discussion before the Institution of Civil Engineers in connection with a paper by Sir F. Abel on explosives. Exceptional dryness of the atmosphere during anticyclonic weather which would make coal dust more dangerous was represented as a possible proximate cause of explosions. Mr. H. Harries, a member of the Meteorological Office Staff who took part in the discussion, contributed a letter to "Nature" upon the subject in which high pressure causing slight dislocation of the strata, rather than low pressure allowing the escape of imprisoned gas, was suggested as an explanation of the facts.

"Colliery warnings," based apparently upon the hypothesis of the influence of the sudden fall of pressure, have appeared from time to time in newspapers and have attracted attention in various ways. Frequent inquiries were made as to the practice of the Office in regard to their issue. In 1908 the Home Secretary directed the attention of the Royal Commission on Mines to the subject, and an official request was received for a statement of the facilities afforded by the Office

in connection with the issue of warnings to collieries, to which a reply was sent to the following effect:

SUPPLY OF INFORMATION TO NEWSPAPERS AND PRESS AGENCIES

The various newspapers and press agencies select for publication such portions of the information placed at their disposal by the Office as they consider of interest to their readers. Some of them publish the whole, others publish extracts, and some only the forecasts for a single district. Others do not make use of the official wording, but employ experts of their own to draft information in special form, or make use of the official information to prepare their own maps and forecasts. Copies of forecasts, remarks and observations are supplied to newspapers in the manner indicated in Chapter I.

Nothing is known at the Meteorological Office of the colliery warnings which appear occasionally in the newspapers. In 1907 there were certain negotiations with the *Colliery Guardian* on the subject of colliery warnings, and it was arranged that notification of approaching rapid falls of pressure should be sent to that newspaper.

NOTIFICATION OF RAPID BAROMETRIC CHANGES

Barometric changes, actual or prospective, form the basis of the method of dealing with the observations reported to the Office, but they are not sent out in terms precise enough for them to be used for the special purpose of warning collieries by a colliery manager who has no specific meteorological training. The Office issues are worded with reference to wind or weather, and no specific regard is paid to the particular features which have been supposed to be of importance in respect of the risk of explosion in collieries; although such special features are of considerable importance as regards wind or weather, and in many cases might be incidentally mentioned in the general inference, they would not be mentioned in the forecasts.

For the reason given above, the information placed at the disposal of newspapers by the Meteorological Office cannot be regarded as suitable in form for use as colliery warnings, and, without local inquiry as to the practice of newspapers in the several mining centres, it would not be safe to assume that the available information is actually placed in the hands of those interested by the morning papers.

There would be no difficulty in formulating day by day the anticipations of the Office as regards barometric changes in such a way that they would be immediately applicable for the purpose of informing colliery managers. The ideas underlying the process are already used in the Office, and it is only a question of expressing them more definitely in words.

For the distribution of such information it would be desirable to send by telegram to the colliery centres, either a daily notification, or a notification as occasion seems to require, preferably the former. The information could then be distributed from the centres by post or telegraph, or by some form of signal. The official to whom the telegraphic reports are sent should keep himself in close touch with the Meteorological Office, in order to avoid misunderstandings.

The reasons for preferring a regular daily telegram to an occasional telegram, or warning, are twofold:—

(1) The Meteorological Office is already responsible for keeping the coasts warned for gales, and it undertakes on certain terms to issue notifications of high tides, spells of fine weather, etc. For one official to have to form an opinion as to the sequence of meteorological changes, and at the same time to keep in mind the multifarious situations which are of special interest to different classes of the community, is likely to be too heavy a responsibility, and as such a system develops, it will become necessary to relieve that responsibility by a division of labour within the Office itself. Apart from considerations of expense, it would be easier for a local official to make and keep himself acquainted with the practice of the work in the Meteorological Office, than for a member of the

Office staff to keep himself in touch with the requirements of the different colliery districts.

(2) The barometric conditions which are of special importance from the point of view of accidents in mines are not yet clearly understood, and probably a considerable period of preliminary investigation by co-operation between the Meteorological Office and colliery experts will be required before the Office can be definitely instructed as to the barometric conditions which should be notified.

Such an investigation cannot be carried on by the Meteorological Office alone, because the facts that ought to be correlated are the *meteorological conditions* and the risk of explosions, or the *explosive conditions*. All that a meteorologist can do at present is to take account of actual explosions which are reported in newspapers. It is the practice with regard to gale warnings to compare the warnings not with the wrecks, but with the gales that may or may not produce wrecks, and some similar provision is required in the case of risks of explosion, of which the Office has, however, no records nor means of obtaining them.

In the present state of our knowledge there is urgent need of a co-operative investigation, such as that indicated, and it is clearly possible. Professor Louis, in his evidence before the Royal Commission (Qn. 45,635), makes the statement that "A great many mines will indicate a change of the barometer before the barometer itself does, and others will answer more slowly." Assuming the indication referred to is a tangible indication, such as that of a fiery state of the mine, the proper setting out of the facts in evidence of the statement, and the inferences to be drawn therefrom, would be of the highest importance.

THE METEOROLOGICAL CONDITIONS WHICH ARE FAVOURABLE FOR EXPLOSIONS

Three different meteorological situations have been assigned in explanation of explosive conditions in mines, viz.:—

(1) The rapid fall of atmospheric pressure incidental to the

passage of a deep cyclonic depression, liberating explosive gas from fissures and cavities in the mines.

(2) Large differences of pressure, as shown in the geographical distribution, possibly causing slight dislocations of strata. The situation numbered (1) may, and on some occasions does, supervene on the situation numbered (2), but not necessarily so, as regards any particular case or any particular colliery.

(3) Anticyclonic conditions causing dryness of the atmosphere, the more dangerous the more prolonged the anticyclone, in those mines which are liable to dust explosions.

SPECIAL FORECASTS

It is possible that on different occasions these several causes are operative to produce dangerous conditions, and all three require different consideration from the point of view of forecasting.

The situation (1), the rapid fall of pressure, can generally be forecasted; but from the nature of the case, since the changes are rapid, the notice beforehand is not very long—twelve to twenty-four hours is the most that can be expected for any part of our islands. Considering the delay that must elapse between the time of observation and the notification, in consequence of the necessary operations of transmission of observations, review of conditions, preparation, transmission and distribution of the notification, it is doubtful whether an official forecast would be more effective than a careful study of a barograph at the colliery. It would, however, certainly reinforce the conclusions from that study, and, so far, be useful.

Situation (2) can be forecasted and notified. Such notification might be of great service, because differences in pressure as regards geographical distribution can only be detected by a comparison of observations from different places. A barograph record would not necessarily give any indication of them. The proper instrument for use locally in this connection is a seismograph.

Situation (3), which merely indicates dry and generally fine weather, would be expressed by the ordinary Office reports and forecasts. Permanence or slow change is a characteristic of this type of weather. With certain reservations regarding positions near the coasts facing north or east, it is an easy situation to forecast. But in all probability the situation would be more efficiently met by an instrument for recording humidity (hygrograph) placed in the air-way which would give directly a continuous indication of the dryness of the atmosphere. There might be difficulties in the working of the instrument on account of dust, but they could probably be overcome.

There are some doubts as to how far the condition of a mine as regards effective humidity is really dependent upon the temporary hygrometric state of the external air, which has enormous seasonal and diurnal variations, and, as the proper remedy in any case is to moisten the workings, the indication ot a self-recording instrument showing that the dryness has passed a certain limit is all that is required to give the necessary clue.

The suggestions, based upon the foregoing considerations, for the organisation and improvement of the facilities for the supply of information to the several collieries respecting barometric changes may be summarised as follows:—

i. The nomination of a "correspondent" in each of the chief colliery districts who should keep himself reasonably well informed about meteorological matters and the practice of the Office in respect of the collection and supply of information, and who should keep a current file of the Daily Weather Report for reference in interpreting the notifications to be sent.

ii. The notification to the correspondents daily (or oftener when necessary) by telegram from the Meteorological Office of the prospective changes in barometric pressure in a form to be agreed upon.

iii. The distribution by the correspondents to the collieries

of the district of the notifications of barometric changes likely to be operative in causing dangerous conditions in accordance with a statement setting forth clearly what classes of conditions will be notified.

iv. The organisation of some means of informing the correspondents as to the prevalence or otherwise of fiery conditions in the circumstances, as regards barometric distribution, notified, with a view to the use of experience for the gradual formation of an improved and more definite statement.

v. The use of the barograph in amplification of, or in correlation with information notified.

vi. The use of the self-recording hygrometer (hygrograph) for determining continuously the variation of humidity of the air in mines.

vii. The introduction, where practicable, of a seismograph to record slight disturbances of the earth's crust which could be correlated with the occurrence of appropriate barometric conditions. A seismograph has recently been installed at Cardiff that might serve as an experimental installation for the investigation of the question.

CHAPTER XXI

THE APPROACH OF DEPRESSIONS

LOCAL DEVIATIONS FROM THE GRADIENT WIND

In this chapter we propose to consider the indications of the approach of depressions. If we were able to deal with a map of the whole earth's surface instead of the limited portion of it which comes under the cognisance of the forecaster day by day the subject would have to be worded as indications of the origin, development or progress of depressions. For the eastern parts of our area the subject already takes that form, but as we have to deal for the most part with depressions already formed which reach our coasts from the Atlantic our attention is largely concentrated on the signs of their approach.

Our ordinary practice in the matter is simple. We watch for the first indications of a falling barometer at the stations on the western fringe of our area. It may be either a fall since the last normal time of reading, or slight downward motion indicated at the time of observation by the barographic record, and it may be merely the backing of the wind at one or more of the western stations in anticipation of the falling barometer. On a day in July, 1910, a calm at Valencia was taken successfully as a prognostic of a coming depression. For some reason which I cannot at present formulate we have never examined the question whether the backing of the wind precedes or accompanies the transition from rise to fall of the barometer, nor the other question, which is perhaps involved in the former, whether the backing wind is in accordance with the barometric gradient or not. The gradient for the

west coast of Ireland or Scotland is uncertain in the absence of readings of the barometer out to sea, and in consequence speculation as to whether the gradient changes before or after the wind backs has had no adequate basis.

As soon as the approach of a depression declares itself we depend upon the rapidity of the fall of the barometer for an indication of its intensity, and upon the behaviour of the barometers in its front as to the path which it intends to follow. We assume that it will follow the direction in which the fall of the barometer is most pronounced, and that the disturbance will be intense if the fall is rapid. Generally speaking, these assumptions are justified, but not always. Other considerations have some weight, but it is not easy to say how much. The distribution of pressure to the eastward, and the way in which it is varying at the time, may suggest that certain lines of movement are the more likely (see p. 173). In winter, when they are most numerous and best defined, the centres of low pressure have a way of keeping to the sea, and to a certain extent they show a partiality for recognised tracks, but they are not by any means amenable to the discipline of fixed rules.

Various suggestions have been made from time to time as to the considerations which govern the motion of cyclonic depressions. Dr. J. Aitken regarded the direction of their strongest winds as the controlling element of their motion.[1] Temperature has often been mentioned as the governing consideration in the selection of their route, but, as pointed out in Chapter V., the distribution of temperature is not symmetrical, and in consequence it is a very difficult element to deal with. It is not so much the actual temperature as the local temperature in relation to its environment that is the consideration really in view. On the method of the polar front, the line of travel is the tangent to the steering line at the centre of the depression, or parallel to the isobars of the warm sector.

[1] "Trans. R. S. E.," vol 40, Part I, p. 131, 1901.

An endeavour to deal with the question from the consideration of pressure and winds alone is to be found in the work of M. Gabriel Guilbert,[1] of the Commission Météorologique du Calvados, who has formulated a new method of anticipating the approach and progress of depressions by studying the relation of the winds to the gradient at the stations represented on synoptic charts. His views were first given to the Societé Météorologique de France in April, 1891. They were subsequently expressed in papers before the French Academy, and were brought into greater prominence by receiving the award of a prize in a competition in practical weather-forecasting in connection with the International Exhibition at Liège in 1905. They are now published in book form, with a preface by the late M. B. Brunhes, of the Observatory of the Puy-du-Dôme. M. Guilbert's attempt to apply the observed variations from the normal in the relation of the observed wind to the gradient is of special interest to the Meteorological Office because during the past ten years we have paid particular attention to the computation of the direction and velocity of the theoretical wind from the barometric gradient and its relation to the observed surface wind. With our exposed situations we are disposed to regard the gradient wind as the normal wind, at least for the upper air, and to look upon the deviation in direction and magnitude of the observed wind from the gradient at any station as due to surface friction and to local circumstances of exposure. But it is clear from any series of observations that the relation of the observed wind to the gradient wind is subject to very considerable fluctuations, and we are accordingly prepared to welcome M. Guilbert's endeavour to interpret these deviations as important indications of the changes of pressure which are about to occur.

M. Guilbert adopts a simple empirical value for the normal

[1] "Nouvelle Méthode de Prévision du Temps," par Gabriel Guilbert. Gauthier Villars, 1909.

wind at any station in relation to the gradient. It is given in the following table.

Gradient in mm. per 111 km.	Normal Wind, Beaufort Scale.	Equivalent in Metres per second.
1	2	4
2	4	8
3	6	12
4	8	16

There are a number of considerations which make it difficult to bring this table into relation with English measures and the method of computing the gradient velocity which we have given in Chapter IV. First, the computation of gradient velocity includes a factor depending upon the latitude, and to be strictly accurate must take account of the curvature; secondly, the proportionality of Beaufort scale to velocity, and therefore to gradient, is not exact; thirdly, the variation of exposure of our stations is known to be considerable, so that a normal relation of wind velocity to gradient suitable for one is not suitable for another. In illustration of this last point let me refer again to the average relation of the velocity of the observed wind as indicated by the anemometers at Falmouth and Pendennis (which are within two miles of each other on our south coast), to the gradient wind. It is represented in Fig. 29. The outer circle representing the gradient wind, and on the same scale the inner curve representing the velocity of the wind as recorded at Falmouth Observatory and the intermediate curve representing the corresponding velocity at Pendennis Castle, show how important a matter the exposure of a station may be. This point is treated fully in "Manual of Meteorology," Part IV., Chapter II.

We must accordingly regard M. Guilbert's scale of equivalents as a comparatively rough working normal, approximating to the result obtained in average exposures. We give here the transcription into British measures.

BEAUFORT SCALE AND M. GUILBERT'S "NORMAL" WIND WITH THE CORRESPONDING GRADIENT WIND.

Wind Velocity, metres per second.	Wind Velocity in miles per hour.	"Normal" Wind, Beaufort Numbers.	Gradient in hundredths of an inch per 15 nautical miles.	Distance apart of mm. isobars in nautical miles.	Distance apart of one-tenth-inch isobars in nautical miles.	Distance apart of 2 mb. isobars in nautical miles.	Gradient Velocity in miles per hour for straight isobars. Latitude 55°; Temperature 60°; Pressure 29 inches.
2	$4\frac{1}{2}$	1	0·5	120	300	180	10
4	9	2	1·0	60	150	90	20
6	$13\frac{1}{2}$	3	1·5	40	100	60	30
8	18	4	2·0	30	75	45	40
10	$22\frac{1}{2}$	5	2·5	24	60	36	50
12	27	6	3·0	20	50	30	60
14	31	7	3·5	17	43	25	70
16	36	8	4·0	15	37	22	80

By comparing column 2 with column 8 it will be seen that M. Guilbert's normal wind is rather less than one-half of the gradient wind, being in fact 45 per cent. of the gradient wind computed at 60° F. and 29 inches of mercury.

It will be understood that when we speak of departures from normal they must be considerable, otherwise they might be covered by difference of interpretation.

The normal wind has also a relation to the isobars or gradient as regards direction. We have already given a number of instances which show that the wind is often actually tangential to the isobars, but there is sometimes incurvature which, as I understood from M. Brunhes's preface to M. Guilbert's book, may be as much as 40° inwards in a cyclone or outwards in an anticyclone without having any special significance. Deviations from the isobar beyond these limits must be regarded as abnormal.

There is another matter which makes the application of M. Guilbert's reasoning difficult. The estimation of the gradient in millimetres of mercury per 60 nautical miles, or in hundredths of an inch per 15 nautical miles, has to be

determined by measuring the distance apart of isobars plotted on the map, or by estimating the pressure at two points one on either side of the station at a known distance apart. There is no essential difference between the two methods, but we will take the former as the one most likely to be adopted by those who work with synoptic charts. The isobars are drawn by interpolation between the readings at the stations, and the details of the shape and position of the isobars depend upon the interpolation. They may in consequence show a distribution comparatively uniform when a greater number of stations would show local variations. If, therefore, we find that the wind as recorded does not agree with the average gradient for the district as shown on the chart, we have always in reserve the possibility that the average gradient for the district is not the local gradient applicable to the particular wind. In the course of investigation of gradient in relation to the upper air this consideration forces itself upon the attention, but its application in regard to M. Guilbert's rules is not so clear. Agreement with the theoretical gradient wind practically implies that the motion of the air is "steady" in the sense that the forces acting upon it are balanced, and that it is not, therefore, subject to acceleration; departure from agreement either as regards direction or force implies that the motion is no longer steady in the sense indicated, consequently acceleration is operative. The deviations from the normal upon which M. Guilbert bases his conclusions may be due in fact to the disturbance of the steady motion which results in the re-arrangement of conditions expressed by the approach or recession of a cyclonic disturbance, but, on the other hand, the signs of the approaching depression may be in reality not departures from gradient wind, but local deviations of the gradient from the uniformity corresponding with the general run of the isobars. Our most careful examinations of hourly charts for certain special occasions lead us to the conclusion that many of the apparent deviations from gradient are really only deviations from an assumed uniformity. Only further

examination can decide between such cases of apparent deviation and cases of real deviation from gradient, of which perhaps it may be said that they must exist, but at the same time they must be transient, because the necessary acceleration of the air to bring it into relation with the gradient is not a long process.

M. Guilbert's rules may be summarised as follows:—

A.—AS REGARDS STRENGTH OF WIND

1. A depression with winds above normal on all sides will sooner or later fill up; one with winds below normal will become deeper, and often depressions which are apparently weak will change into cyclonic storms.

2. Those parts of a depression in which the winds are below normal indicate directions in which the depression may advance; thus, when a depression consists partly of winds that are above normal and partly of winds that are below normal it will move in the direction of "least resistance," that is in the direction where the winds are below normal.

3. Pressure increases from right to left across the line of winds too strong for the gradient. Such winds cause an increase of pressure on their left as they move.

B.—AS REGARDS DIRECTION, DIVERGENT AND CONVERGENT WINDS

Winds are divergent from the normal direction if they blow away from a low pressure area or in opposition to the normal direction corresponding with the isobars. A wind below the normal for its gradient is divergent in respect of the component which must be superposed upon the normal wind to give the actual wind.

Divergent winds indicate the approach of a low pressure system.

Winds are convergent if they blow more directly towards a low pressure area than a normal wind. A wind which exceeds the normal is convergent in respect of the component, which must be added to the normal to give the actual wind.

Convergent winds indicate the departure of a low pressure system or a rise of pressure.

In a preface to M. Guilbert's book M. Brunhes introduces an electrodynamic analogy for the sake of illustrating the application of these laws. A horizontal magnetic field will repel towards the left of its own direction a vertical electric current which produces a magnetic field of circular lines concurrent with the repelling field, and attracts the current if it is on the other side, so that it produces a field opposing the original field. Regarding the original field as the analogue of the normal wind and the deviations therefrom as due to the concurrence or opposition of a field of circular lines of force to the left or right, the normal field will repel the one or attract the other. Similarly the distant current will be attracted by a field which shows "divergence," and repelled by one showing "convergence." In this way a mental picture may be formed which assists the memory in regard to M. Guilbert's rules.

Another way of forming an idea of the vector representation is to consider the deviations from normal as a system superposed upon the original normal wind system. This superposed system will be anticyclonic when the winds are divergent and cyclonic when the winds are convergent. The existence of a superposed anticyclonic system in any locality shows that the barometer will fall there, and *vice versâ*.

EXAMPLES OF M. GUILBERT'S FORECASTS

M. Guilbert gives a large number of examples of the application of his rules in his book already referred to, and he seems to be particularly successful in identifying the approach of deep depressions. I shall quote one or two examples taken originally from M. Brunhes' report upon the Liege competition, with charts representing the meteorological conditions at the time as they were presented to us in this country. In order to show the distribution of pressure by means of isobars in greater detail and thus facilitate the determination of the

local gradient I have had the charts plotted according to successive five-hundredths of a centimetre-gramme-second atmosphere. Each step is, therefore, 2 millibars, about 1·5 millimetres, or six-hundredths of an inch, instead of 5 mm. as in the Continental charts and the tenth of an inch in ours. The examples are as follows :—

August 31, 1905 (Figs. 181A, 181B).—Forecast based on the morning map: "New depression with a fall of pressure from Archangel to Scotland: the Russian depression passing to the east or north-east."

The grounds for this forecast are: winds too strong for the gradient in the case of the Russian depression (Wisby north-east, 8, Neufahrwasser north, 7, Swinemunde north, 7), south-south-east wind at Bodo, and north-east at Haparanda, giving an anticyclonic circulation. Winds too light for the gradient from Bodo to Ireland.

September 4, 1905 (Figs. 182A, 182B).—"To-morrow there will be a rise over Provence and Poland, a fall will have set in afresh on the west of Europe, a new depression approaching Ireland and threatening the west coasts of Gascony and the south-west of Norway; the fall, it appears, ought to be greater in Brittany than over the rest of France."

The grounds for this forecast are :—

First, two slight indications of falling barometer, one in the west of Ireland and the other over Spain and at Biarritz. Secondly, from Christiansund to Biarritz, winds which are "divergent" with reference to a minimum over the northern ocean with which only the south-south-west currents of Ireland and Scotland are properly concordant. Thence may be inferred a certain fall from the north of Norway to the Gulf of Gascony throughout the zone where there are divergent winds. But the divergence attains its maximum in Provence, where the north-west winds are in marked excess of the normal. At the same time that these abnormal winds tend to show a rise over Provence, thus disposing of the cause of the north-west winds which would be forecasted on the classical method, they tend

1905. August 31, 8 a.m.

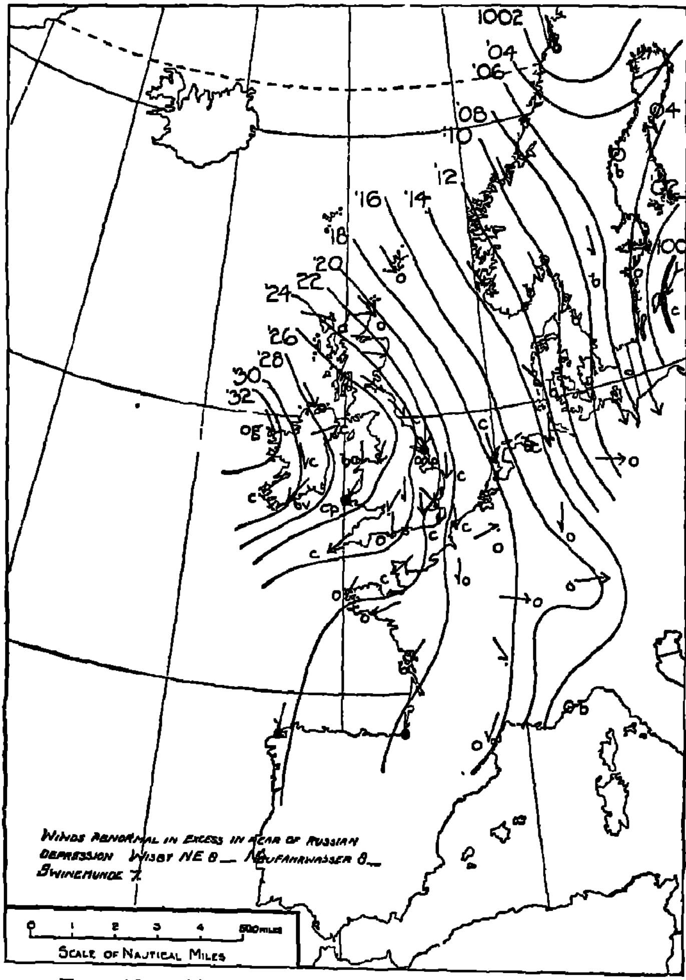


FIG. 181A.—Illustrations of M. Guilbert's Forecasts (1).
(Pressure in millibars. initial ten omitted.)

Forecast: "New depression with a fall of pressure from Archangel to Scotland: the Russian depression passing to the east or north-east." For result see Fig. 181B.

1905. September 1, 8 a.m.

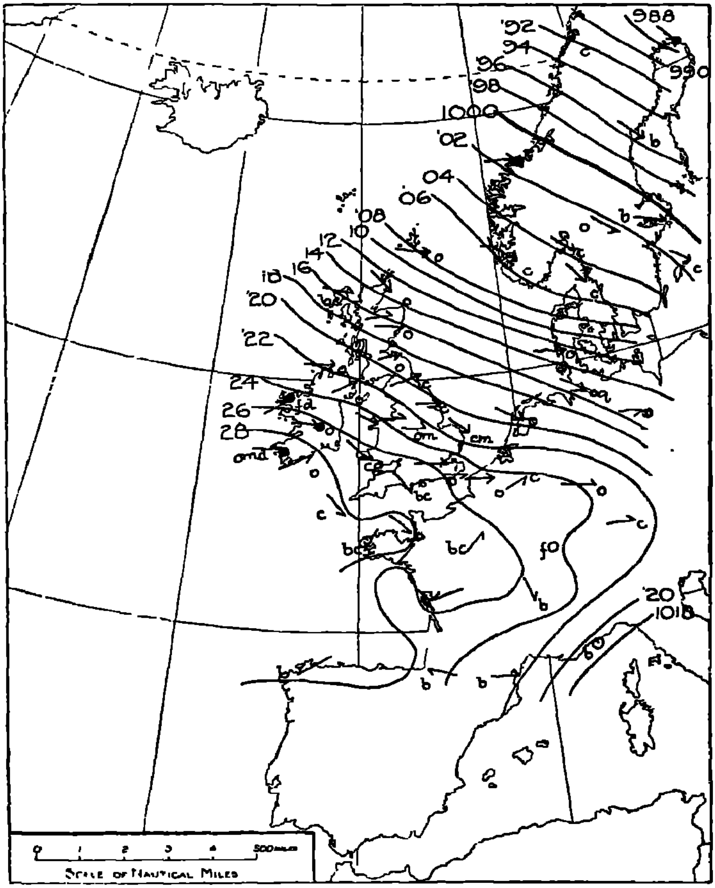


FIG. 181B.—Illustrations of M. Guilbert's Forecasts (1).
(Pressure in millibars, initial nine or ten omitted.)

1905. September 4, 8 a.m.

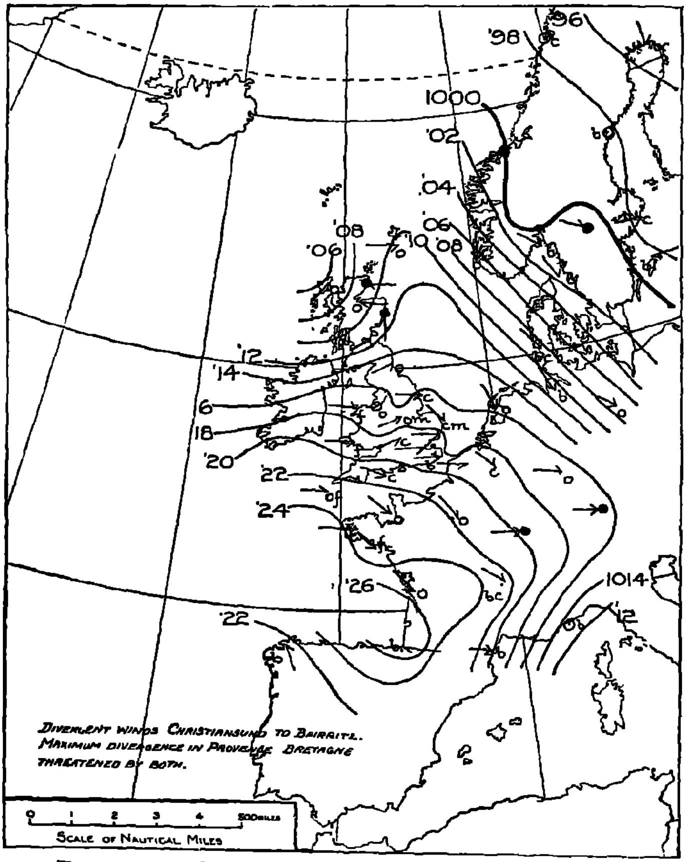


FIG. 182A.—Illustrations of M. Guilbert's Forecasts (2).
(Pressure in millibars, initial nine or ten omitted.)

Forecast : "To-morrow there will be a rise over Provence and Poland, a fall will have set in afresh on the west of Europe, a new depression approaching Ireland and threatening the west coasts of Gascony and the south-west of Norway ; the fall, it appears, ought to be greater in Brittany than over the rest of France." For result see Fig. 182B.

1905. September 5, 8 a.m.

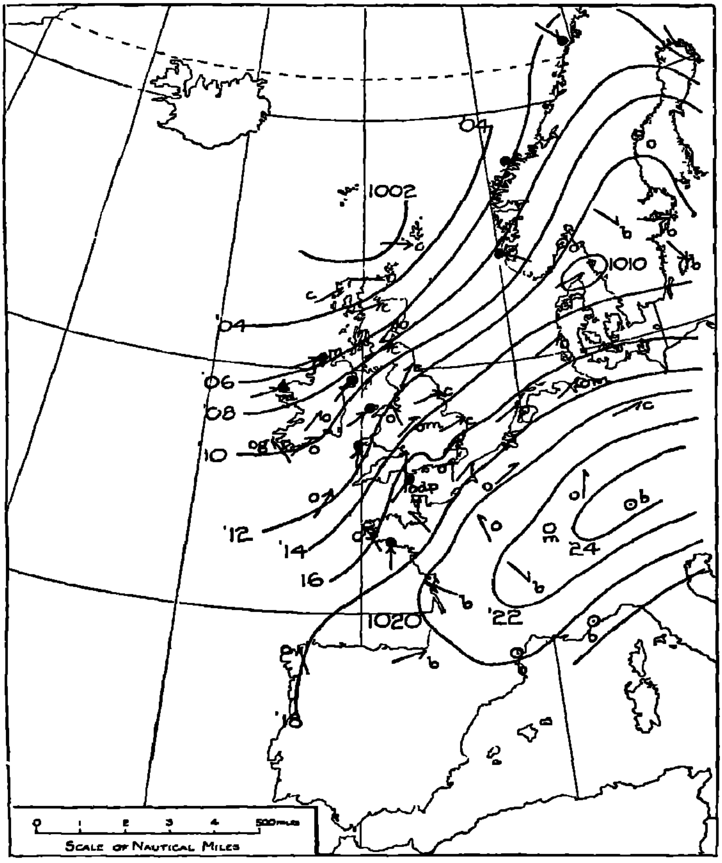


FIG. 182B.—Illustrations of M. Guilbert's Forecasts (2). (Pressure in millibars, initial ten omitted.)

1893. February 20, 8 a.m.

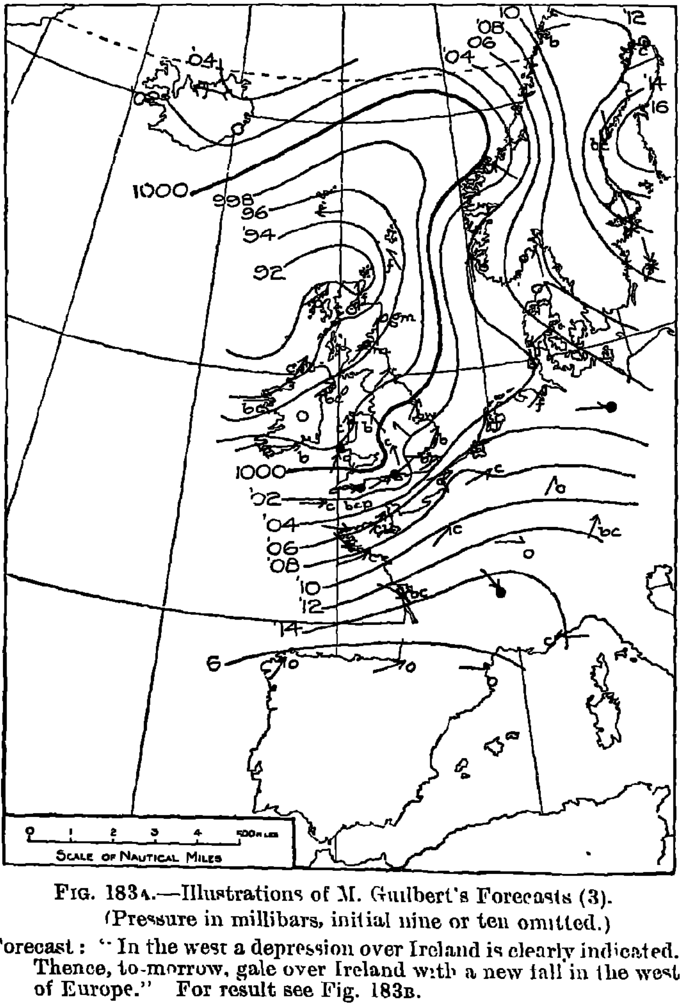


Fig. 183A.—Illustrations of M. Guilbert's Forecasts (3). (Pressure in millibars, initial nine or ten omitted.)

Forecast: "In the west a depression over Ireland is clearly indicated. Thence, to-morrow, gale over Ireland with a new fall in the west of Europe." For result see Fig. 183B.

1893. February 21, 8 a.m.

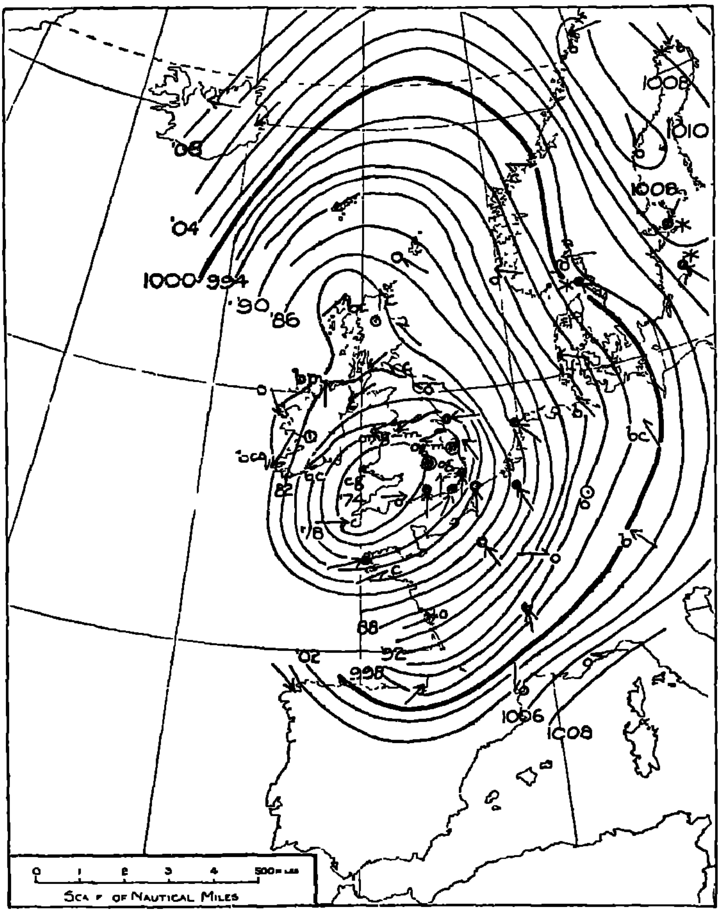


Fig. 183b.—Illustrations of M. Guilbert's Forecasts (3).
(Pressure in millibars, initial nine or ten omitted.)

to form a minimum of pressure over the Gulf of Gascony (pressure falls to the right of a wind abnormal by excess, and rises to the left), already threatened by the depression over the ocean. The fall ought to be greatest there if the fall setting in over Ireland does not extend so as to join that of Gascony. Brittany, where the winds are zero or divergent and which is thus a region of feeble resistance, is therefore threatened at the same time by falls to north and south. The fall ought, therefore to be greater there than elsewhere over France.

February 20 (Figs. 183A, 183B).—"In the west a depression off Ireland is clearly indicated. Thence, to-morrow, gale over Ireland with a new fall in the west of Europe."

This is a striking example of the forecast of a gale which eluded our vigilance.

The grounds in this case were "divergent" winds in the west (Scilly west, 8; Ushant north-west, 7; Cherbourg south-west, 5), allowing the prognostic of the new fall.

It will be noticed that in some of the cases the evidence mentioned as translated from M. Brunhes' report is not given on the maps reproduced, which are purposely constructed from the data of our own daily telegraphic reports, and particularly in the last and most important case the reasons are not very explicit.

A number of additional examples are given in M. Guilbert's book, to which the reader must be referred for further details. I must confess that the confident application of the method requires more experience than at present I possess. M. Guilbert would almost certainly regard the area of our maps as too much restricted in longitude for effective forecasting, and he seems to detect divergent or abnormal winds in regions that would seem to us unrelated to the approaching disturbances. In the attempts which I have made to test the method in the current practice of my own office I have found that winds leading away from a low pressure area often indicate a coming fall of barometer, but I have not been able

to satisfy myself that they were not in accord with the gradient. They were certainly "divergent" from the wind system behind them, but not from the isobars in their immediate neighbourhood.

It is possible that if we omitted every alternate isobar from our own charts, and so used a 5-millimetre interval, we might make a different estimate of the gradient and attribute abnormality which does not show on the more detailed chart. This point is a particularly interesting one for our work because there are undoubtedly a number of cases in which the winds are not in accord with the gradient, and we should like to know the reason for the deviation. Hitherto we have been unable to deal with the question because we have had no definite knowledge of the allowance that must be made for surface friction or inadequate exposure. Statistical answers to these questions are, however, now completed. They are to be found partly in a paper by Mr. J. Fairgrieve "Geophysical Memoirs, No. 9" (M.O. publication 210, 1914), and in summary in "Manual of Meteorology," Part IV., Chapter II. (Cambridge University Press. 1919). We are now in a position to examine the application of M. Guilbert's suggestion with all the necessary information. The inquiry would be laborious, but the correction of the winds shown on maps for the exposure of the stations would be in itself a valuable study, because it would eliminate one of the elements of disorder in the map as it exists at present.

CHAPTER XXII

MOVEMENTS OF DEPRESSIONS—ISALLOBARIC CHARTS

In considering the indications of future weather contained in the present meteorological conditions we have, in accordance with established custom, confined ourselves to the representation of current conditions by means of isobaric lines at sea level. The first and most important conclusion drawn from the study of synchronous charts was that the pressure conditions represented by certain groups of isobars of recognisable shape, and the weather associated therewith travelled across the map and thus enabled notice to be given of the approach of weather of various kinds to districts included within the boundary of the region of observations. The next step in the study of the subject is clearly the determination of the direction and the speed of travel of the recognised groups, and as the cyclonic depression is the best defined of all the recognised groups of isobars, attention has naturally been directed largely to the movement of cyclonic depressions with the hope of formulating working hypotheses, if not physical laws, as to the course which will be pursued by a depression when its existence has once been identified.

A general conclusion is easily arrived at. A large majority of depressions have a general motion from west to east, with more or less tendency towards the north, so that large numbers of them travel on some course between east and north-east, or perhaps a point or two beyond north-east. We have already pointed out that it is a matter of the greatest importance as regards the weather in a particular locality whether the centre of a depression passes to the north or to the south of the locality. In winter, for example, it makes the difference between mild rainy weather and a blizzard of snow. Hence, greater precision than the accepted general

statement affords has been sought in regard to the paths of the centres of barometric depressions or of detached anticyclones. The quest has been a very disappointing one. Long experience leads one to surmise that the guiding influence is in some way or other coastline. The North African coastline guides the north-east trade-winds, the coastline of the New World the paths of West Indian hurricanes and the cyclonic depressions of the western Atlantic. In like manner the general coastline of Europe, France, Netherlands, Norway, guides many of our depressions while others are guided by the higher hinterland above 200 metres which gives a sort of coastline from Spain to the Ural mountains. But it is all very vague. I do not know any more eloquent picture of the difficulty of this aspect of the general meteorological problem than the chart of the paths of the centres of depressions over North-western Europe in the month of October, prepared by General Rykatchef, Chief of the Russian Meteorological Service, and reproduced here in Fig. 184. No path can be drawn so tortuous and so out of the way that we can fairly say it must be ruled out as a possible path for the centre of a cyclonic depression.

Fortunately, or unfortunately, the problem is not generally presented to working meteorologists in the horrifying form of a collection of all paths. The question appears less unapproachable if we deal with a summary of the paths for a year or a month. We can then group the complex of paths into something like order by associating together those which are more or less alike. Figs. 185, 186, 187 give the generalised paths of depressions in the neighbourhood of the British Isles in the years 1907-8-9—that is, since we have received daily telegrams from Iceland. Before that time things seemed simpler. A large number of depressions were hypothetically centred between our islands and Iceland, and these formed by far the largest group, the path of which was represented by a straight line to the north-west of us, and was regarded as the main route for the Atlantic cyclones. A summary view of the numbers of depressions which have visited the different areas

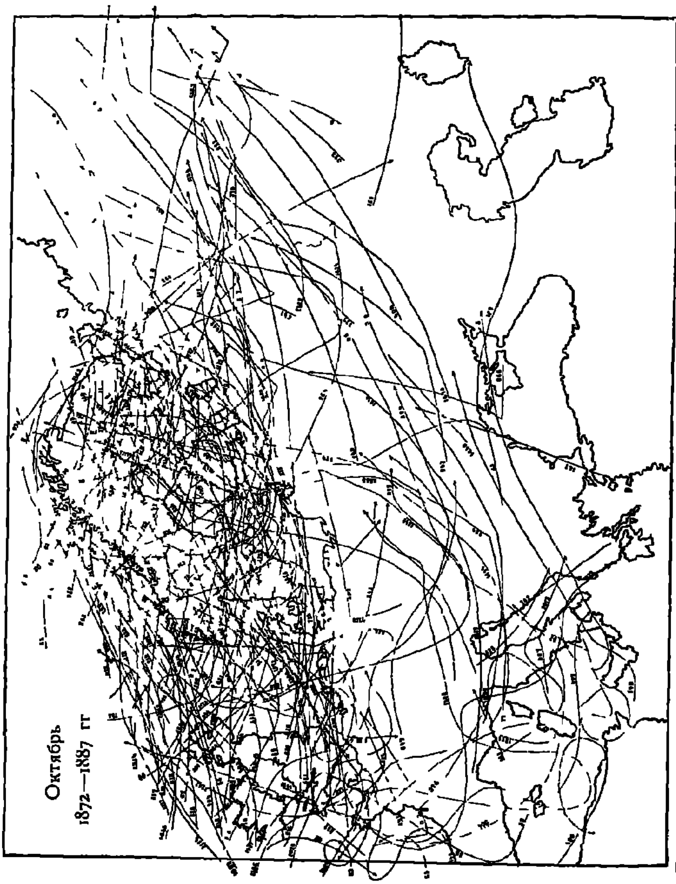
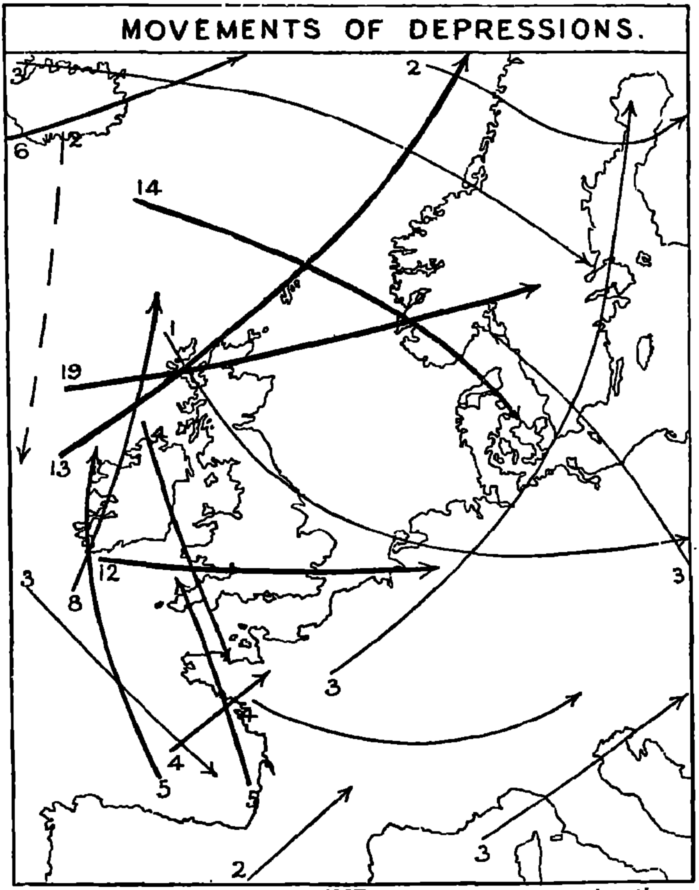


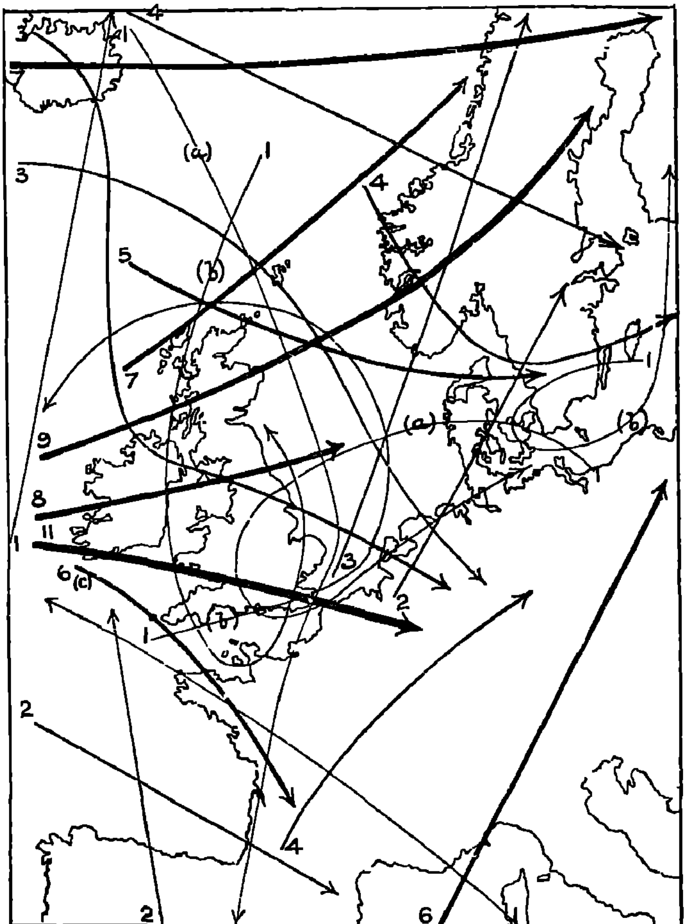
FIG. 184 —Tracks of Cyclones over Europe in October, 1872—1887 "Transactions of the St Petersburg Academy of Sciences" (Rykatchef).

1907.



The number of depressions in 1907 referred to each general path is indicated at the commencement of the lines.

Movements of Depressions. 1908

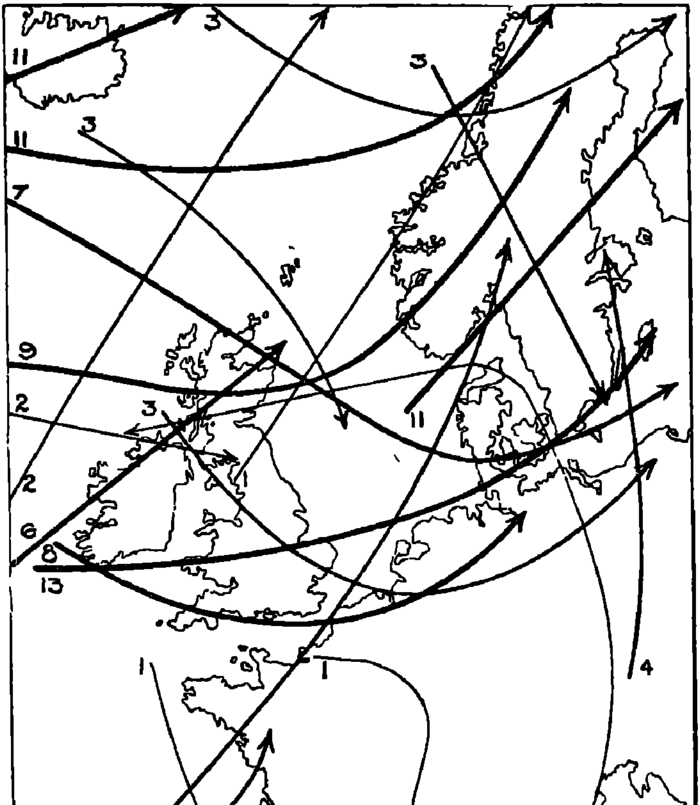


(a) Cold and snowstorm disturbances, Feb 27 - March 5
(b) " " , April 19 - 26
The path of the snowstorm of Dec 29th is included in the track (c)

The figures at the commencement of the lines give the number of depressions referred to the several paths.

FIG. 186.

Movements of Depressions. 1909.



The figures indicate the number of depressions following each path. 12 very irregular paths are omitted.

FIG. 187

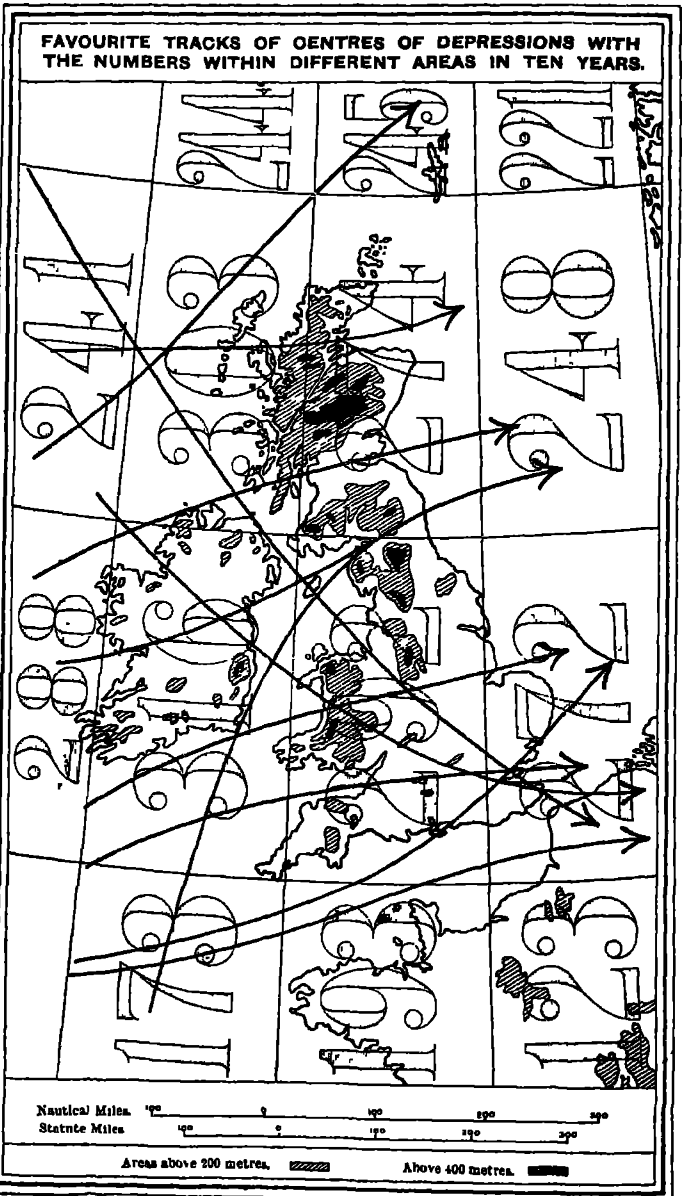


FIG. 188.—Numbers of Centres of Depressions which have been located within certain Squares of Five Degrees of Latitude and Longitude in the Ten Years 1907 to 1916.

of our maps within the ten years 1907 to 1916, and the tracks across our island which may be regarded as favourites is given in

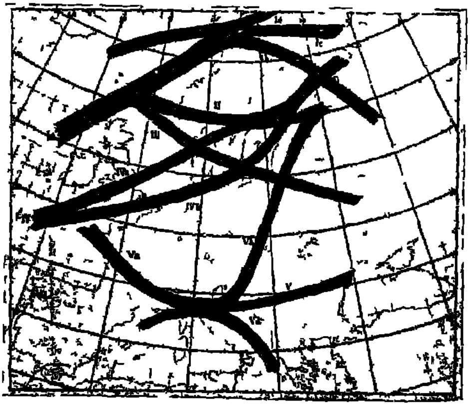


FIG 189 —Principal Tracks of Barometric Minima over Europe, 1876—1880 "Deutsche Seewarte, Monatliche Uebersicht der Witterung, 1882" (Van Bebber)

Fig 188 taken from the 'Weather of the British Coasts' (M O. publication, No 230)

By the process of segregation of the more or less like we

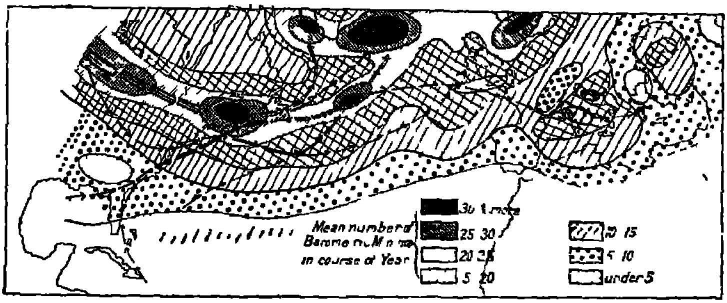


FIG 190 —North Atlantic Ocean Distribution of Barometric Minima. "Deutsche Seewarte, Atlas des Atlantischen Oceans" (Koppen).

can gradually simplify the aspect of affairs until we arrive at the diagrammatic results represented by Figs. 189, 190, the one by Professor Van Bebber, which shows us the chief paths of the centres of cyclonic depressions over north-western

Europe, and the other by Professor W. Koppen, which shows the chief loci of the barometric minima over the Atlantic.

It is certainly disappointing that the paths of barometric minima are not more subject to rules which allow themselves to be detected and formulated. Principles and rules in these matters there doubtless must be, but up to now they have not allowed themselves to be reduced to words except in the form of very general statements applicable only on the average. In dealing with this matter the forecaster must make use of his own experience of weather charts, and if he has none he will find the acquiring of it to be a most interesting but rather exasperating study, assisted materially at the present time by Col. Gold's analysis of the various situations referred to in Chapter VI. Meanwhile no forecaster can afford to depend upon the average; he has to deal for good or ill with the individual depression. It is not, therefore, matter for wonder that after an experience extending altogether over fifty years, during which among others, the hopes of predicting the advent of depressions crossing the Atlantic have been disappointed, meteorologists should begin to speculate whether, after all, it is the distribution of pressure which we ought to map. It is, of course, possible that some other mode of representation of the conditions might lead to more regular results.

Dr. Nils Ekholm, of Stockholm, has led the attack in this direction in a series of papers on the non-periodic variations of pressure, in the "Meteorologische Zeitschrift."[1] He has experimented particularly with the plotting of pressure differences since last observation instead of the actual pressures at the time of observation. He uses charts of *isallobars*—that is of equal pressure differences in a given interval—instead of, or in addition to, the charts of isobars. No doubt every institute that deals with daily weather charts and forecasts has always noted the "changes since yesterday" in the form of specially prepared charts or in some other manner, but Dr. Ekholm has pushed the systematic investigation of charts of isallobars. We give here

[1] "Meteorologische Zeitschrift," vol 24, pp 1, 102, 145. 1907.

a pair of charts of isallobars for the intervals 7 a.m. to 6 p.m. of December 19 and 6 p.m. of December 19 to 7 a.m. of December 20, 1909 (Figs. 191, 192), as examples of the mode of representation. It will be seen that similar groups of isallobars appear on both maps, so that the isallobaric groups may be regarded as travelling as well as the isobaric groups. Dr. Ekholm's contention is that the travel of the isallobaric groups is more regular than that of the isobaric groups, and that in consequence the preparation of maps of isallobars in addition to the ordinary charts of isobars would be a productive supplement to the work of the daily weather service. The inferences may be illustrated by Figs. 193, 194, which represent the paths of isallobaric groups and of depressions respectively during the period of February 5—13, 1904. The reporting of barometric tendency or change of pressure in a given period was introduced into the International Meteorological Service in 1911 and the period of three hours was selected. The interval to be selected as the one during which the change shall be estimated naturally gives rise to the consideration as to what an isallobaric chart really means, or how the distance apart of consecutive isallobars is related to the corresponding factor for isobaric charts, that is to say, to the barometric gradient. For information on these points we must refer to the original papers. We can here only suggest that since something different would be obtained for isallobaric charts for an interval of twenty-four hours, twelve hours, six hours, or three hours, it would appear that the rate of change actually in progress is the only ultimate resting place if one begins differentiating, and that the interval that gives the nearest approach to the differential coefficient with regard to the time is most likely to lead to a physical meaning.

There is another point which may be mentioned which concerns the relation of isallobars to wind. Suppose, for example, that we plotted the change in pressure during twelve hours, and the corresponding vector change in the wind, and we apply it to an imaginary case in which the change in twelve hours has been the passing away of baro-

Chart of Isallobars.

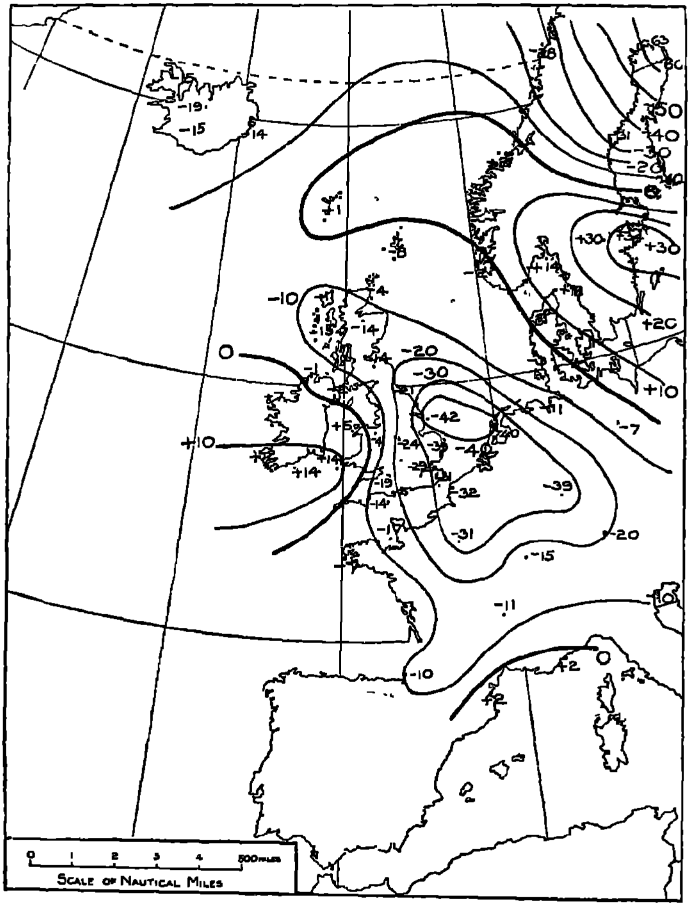


FIG. 191.—Changes of Pressure in the Interval 7 a.m. to 6 p.m., December 19, 1909.

The changes are expressed in hundredths of an inch of mercury under standard conditions.

Chart of Isallobars.

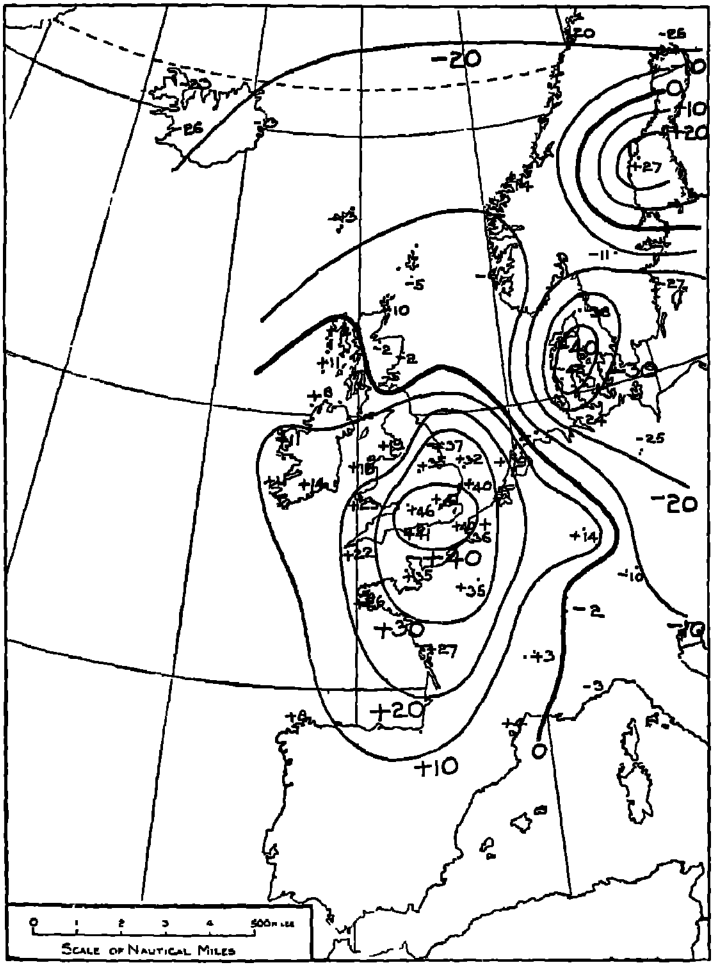


FIG. 192.– Changes of Pressure for the Interval 6 p.m., Sunday, December 19, to 7 a.m., December 20, 1909.

The changes are expressed in hundredths of an inch of mercury under standard conditions.

Paths of Isallobaric Groups, February 5—13, 1904 (Ekholm).

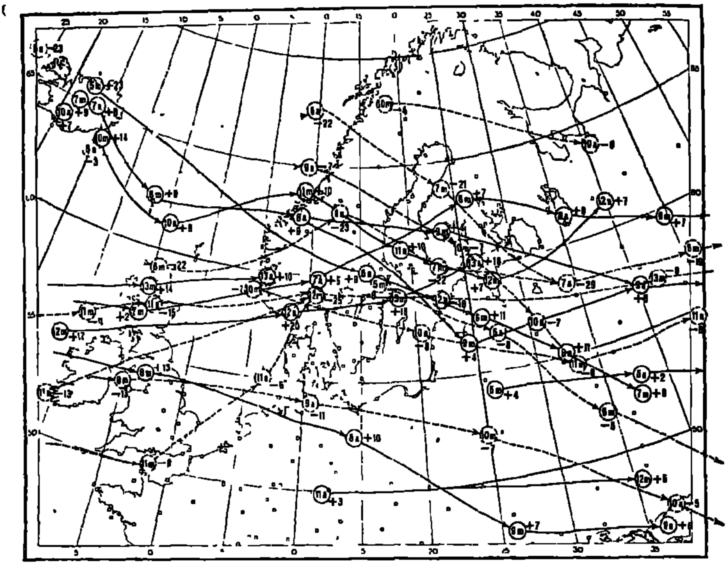


FIG. 193.— - -○ - > Areas of fall. —○→ Areas of rise of pressure. The circles denote the position of the centre, the included number the day of the month, *m*. morning, *a*. afternoon; the number by the side of the circle is the range of the 12-hourly change of pressure in millimetres.

Paths of Depressions, February 5—13, 1904 (Ekholm).

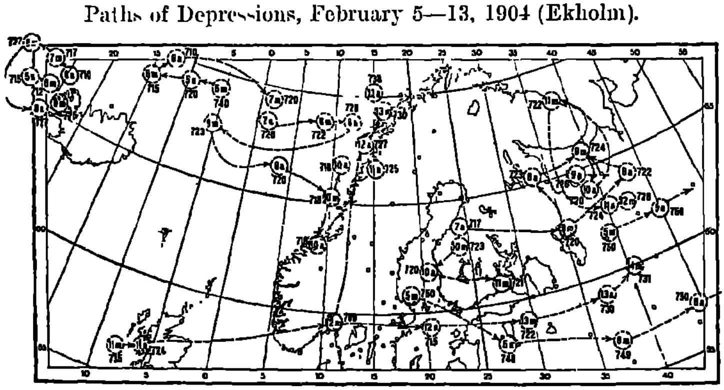


FIG. 194.— —○→ Paths of Cyclones. The circles denote the position of the centre, the number enclosed the day of the month, *m*. morning, *a*. afternoon; the number by the side of the circle is the pressure in millimetres.

metric differences leaving uniform pressure behind. In this case the isallobaric charts would be the exact inverse of the pressure charts, and to produce the calms appropriate to uniform pressure the original winds would all have to be reduced to zero, or the isallobaric winds would be just the reverse of the pressure winds. But the winds of a reverse pressure distribution are not exactly the reverses of the original winds owing to the correction for curvature and the deviation from the tangent; hence the study of the isallobaric charts in relation to the changes of wind offers an opportunity for exhibiting the wind characteristics in a special manner.

Isallobaric charts for the three hours 4 h. to 7 h. are now drawn daily in the Meteorological Office and have found a place in the British Section of the Daily Weather Report, but in this matter we are sensible of our extreme western position on the map: by the time the isallobaric lines have become sufficiently well marked, they have mostly lost interest for our islands.

Ekholm's method of isallobars has been revived or separately originated in the French Military Meteorological Service by M. Schereschewsky.

And, on the other hand, the difficulties arising from discussing differences instead of the pressures themselves, are set out by E. G. Bilham,[1] of the Meteorological Office, London, though he allows that the differentiation may help to resolve complex situations which are intractable when expressed in pressures.

"It is clear that the value of the isallobars is largely dependent upon the accuracy with which they can be drawn. According to present practice in England the unit for barometric tendency is the half-millibar, consequently the values to be reported are frequently but small multiples of the unit and the uncertainty in drawing the isallobars is relatively great. It is equivalent to drawing isobars for each millibar among barometric readings expressed only to the nearest half-millibar. Even with this rough method of procedure the isallobaric chart cannot fail to be of material assistance, and rough approximation to the forms

[1] "Geografiska Annaler," Stockholm, vol. 3, p. 336, 1921.

investigated in this paper are frequently to be seen on the charts in the Daily Weather Report.

"When the pressure distribution is accurately known both at the beginning and end of the time interval, the point at issue is whether the isallobaric chart is capable of affording any additional information, or of displaying the available information in a more effective way. We have found in the case of small depressions uncomplicated by other systems that the isallobars are merely a sort of composite picture of the two sets of isobars and no additional information is imparted by them. The same is true of large depressions. In most cases we found, in fact, that the isallobars tended to be more complex than the pressure distributions giving rise to them. No additional information as to the course taken by the depression in moving from its initial to its final position is afforded by the isallobaric chart since, as has previously been pointed out, the isallobars depend only on the initial and final conditions, and not on intermediate stages.

"When the distribution is complex, however, the isallobaric chart is of value since it performs the function of separating the active from the quiescent features of the pressure distribution. Since complexity is the normal condition of isobaric charts, any method whereby certain outstanding features could be disentangled from their surroundings would seem to be worthy of attention. An isallobaric chart is clearly capable of presenting to the eye a picture of the state of affairs which would not be readily perceived on the ordinary chart."

CHAPTER XXIII

STATISTICAL METHODS FOR LONG PERIOD AND SEASONAL FORECASTING

A GREAT deal of work has been done in recent years with the view of determining the sequence of weather from season to season, or from year to year, and detecting in the historical sequence laws by means of which the weather of the future years or future seasons can be anticipated. The form which this endeavour has taken most frequently is the detection of a natural periodicity in the sequence of the meteorological elements. In the year 1890, Professor Brückner, of Berne, published a work, entitled "Klimaschwankungen,"[1] in which he brought together all available records of the sequence of rainfall, heights of rivers, levels of lakes, and other information connected with the fluctuations of rainfall, and from the collected evidence concluded that a variation of rainfall, with an average period of thirty-five years, was indicated. The sequence of wet periods and dry periods is as follows:—

Wet Periods.	Dry Periods.
1691—1715	1716—1735
1736—1755	1756—1770
1771—1780	1781—1805
1806—1825	1826—1840
1841—1855	1856—1870
1871—1885	

The maxima during the last hundred years were found to be in the years 1815, 1846—50 and 1876—80, the minima in 1831—35 and 1861—65.

[1] Eduard Brückner, "Klimaschwankungen seit 1700 nebst Bemerkungen über die Klimaschwankungen der Diluvialzeit," Wien, 1890. Ed. Hölzel.

The late Mr. H. C. Russell, of Sydney, suggested a period of nineteen years for the variation in the rainfall of Australia; and Dr. W. J. S. Lockyer, in an investigation of the meteorology of Australia and South Africa, has arrived at curves of variation which again convey the suggestion of a period of nineteen years. The same period has been adopted by Colonel Rawson in the detection of a sequence of seasons in South Africa; in this case the variation that is sought to be identified is the change in position of the anticyclonic area which is to be found at some position of higher or lower latitude in the region of the South African coast. There is at once a fascination and a curious inconclusiveness about many of these attempts to identify the period of variation of the meteorological elements. The periodicity shows itself when records for long intervals are studied, but it is apt to be illusory as a guide to the meteorological character of any particular year. An example of the fascination and the difficulty here referred to may be given from the consideration of the seasonal variation of rainfall in our own country. Nothing is more certain about the seasonal variation of that element than that the rainfall tends to a maximum in October and a minimum in March; any curve of average monthly values taken for a long period of years will give that result, and, consequently, one is perfectly justified in assuming that the assignment of a seasonal periodicity in rainfall with a maximum in October represents something real: yet if one were to hazard a prediction that the coming month of October will be the rainiest month in the current year the facts might belie the prediction. Quite a large number of similar instances could be quoted. Nothing is more certain, for example, than that there is a diurnal variation in the height of the barometer, obvious upon every barogram in the tropics and sensible even in this country, which has two maxima in the day, one at 10 a.m. and the other at 10 p.m. No meteorologist of experience would have any hesitation in asserting the existence of this diurnal or semidiurnal variation as a fact; yet there are probably

hundreds of persons in this country who have watched a barograph trace for years and have never realised the existence of the oscillation. It is, in any case, comparatively small, and as a general rule it is overlaid by and concealed under the non-periodic variations of the barometer which are characteristic of temperate latitudes. It invariably appears in the means of hourly readings for a considerable number of days, and with experience of this kind meteorologists are disposed to regard the periodic variations, that suggest themselves when the means for long series of observations are analysed, as real phenomena of which account will be taken in considering the prospects of weather so soon as the subject has been more fully investigated.

One of the most frequently suggested periods in the earth's weather is that of the recognised period in the frequency of sunspots, which is approximately 11 years. The suggestion of an 11 years' periodicity has been made with regard to rainfall in India, cyclones in the Indian Ocean, rainfall in Scotland, and even in the fluctuations of business regarded as dependent upon meteorological conditions by the late Professor W. S. Jevons, of Manchester and his son, Professor Jevons, of Cardiff.

The question of the detection of actual periodicity is one of great interest to the meteorologist, but is full of difficulty. A series of figures is strictly and exactly periodic only when the same figures recur after a fixed interval. Very few of the series which have been used to suggest periodicities comply even approximately with this rule. The example which comes nearest to satisfying the condition, so far as I know, is the sequence of the wheat crops of Eastern England between 1885 and 1905.[1] The number of repetitions of the same amount of crop after a period of eleven years is certainly astonishing. Eleven years always suggests sunspots, and I may therefore mention that some years ago I received from Uganda a curve of monthly variation of the level of the water in Lake Victoria for

[1] "The Air and its Ways," p. 175, Cambridge University Press, 1923.

about ten years. By way of comparing it with something, I had the corresponding curve for sunspots set out below it. The agreement was remarkable and was continued in successive years as they came in. For those years, at any rate, the sunspot numbers would have furnished a satisfactory indication of the water-level.

Another direct application of solar observations to the forecasting of weather is suggested by H. H. Clayton in a paper on "Variation in Solar Radiation and the Weather,"[1] though in this case the forecast only extends for two or three days ahead. The author compares the values of solar radiation with the temperature at Buenos Aires, and, from the results which he has obtained, concludes that every high value of solar radiation is followed three or four days later by high temperatures at Buenos Aires. A diminution of the temperature of the air gives rise to rain, while a rise of temperature is generally attended by fine weather. Consequently a decrease of solar radiation is followed three or four days later by a fall of temperature in Central Argentina, and also by rain at about the same interval. These results have been used by the Director of the Argentine Weather Service for forecasting temperature and rainfall; the values of solar radiation are available the day after observation so that temperature can be forecasted about one and a half or two days ahead.

I understand from Mr. J. Baxendell, of Southport, that he has demonstrated the existence of a smooth harmonic curve with a period of 5·1 years in the averages of wind direction for Southport, and has in like manner found other periods in the meteorological elements for Britain.[2] Those are, however, underlying periods which are undoubtedly real, but are overlaid by other fluctuations.

It is usual to identify periods by noting the salient points, but unless the variation is on a very large scale compared with the mean values, this method is liable to be misleading on account of the influence of temporary disturbances. The most satisfactory way of ascertaining whether there is a

[1] "Smithsonian Miscellaneous Collections," vol. 71, No. 3.
[2] See Annual Reports of the Fernley Observatory, Southport, 1919 and 1920.

period of a definite number of years, as, for example, 11, in any series of numbers is to add the numbers together, 1 to 12, 2 to 13, 3 to 14, and so on throughout the series. By so doing the variation which is periodic in 11 years is left undisturbed. All the other periodic variations incommensurable with 11 years will be obliterated if the series is sufficiently long, and will tend to become obliterated even with short series. The examination of the sequence of numbers which results by forming additions in the manner indicated, gives a satisfactory criterion as to the existence and the magnitude of the variation of the period suggested. This is, in crude form, the method adopted by Professor Schuster in the formation of a periodogram for the examination of the periodicity of any long series of records. He forms the appropriate sums for a series of selected periods, and by examination of the resulting curves, or by the determination of the "first harmonic component," he is able to select those periods which show persistent recurrence by the tabulation of the magnitudes of the components of successive periods. From an examination of a long series of rainfall values he has concluded that the most persistent period is that of 4·79 years, and that the 11 years' period, which is very pronounced in the rainfall results for the last century, is not so persistent when one takes into account longer series of values.

From an examination of the curves representing the variation of pressure at many stations Sir Norman Lockyer and Dr. W. J. S. Lockyer assigned a 3½ years' period to the oscillations of pressure.

The existence of a period in the sequence of weather has sometimes been used tentatively for forecasting coming seasons, but I am not aware that this has ever been done officially. The application of the period law to any individual year is too much subject to exceptions which are not regarded with favour in the consideration of official forecasts.

Endeavours have been made to connect atmospheric disturbances with sunspots by suggesting a periodicity in deep depressions coincident with that of sunspots on the sun's

disc, that is to say, approximately with the rotation of the sun upon its axis. Various other periods of the recurrence of gales or deep depressions have been elaborated from the examination of barographic records. However suggestive the recurrences may be, they have not yet proved themselves sufficiently regular for reliance to be placed upon them in the anticipation of weather.

Another and altogether different mode of using the statistics of past weather for anticipating the future is that based upon the comparison of the sequence of seasonal values for one element in one locality with the subsequent sequence

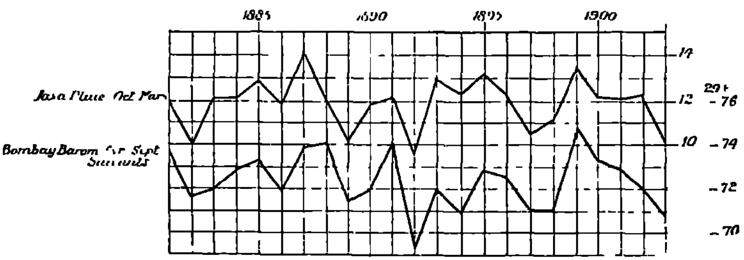


FIG. 195.—Java Rainfall (October to March) and the subsequent Pressure (April to September) at Bombay. "Transactions of the Swedish Academy of Sciences," 45, No. 2, 1909. (Hildebrandsson.)

of some other element in a different locality. Much work has been done in inquiries of this kind by Pettersen in connection with the temperature of the Atlantic and its relation to the weather of the adjacent countries, by Meinardus upon the relation of average pressure differences and the subsequent seasonal temperature of northern Europe, and especially by Hildebrandsson in his papers on "Centres of Action of the Atmosphere," in which he has traced the similarity between the sequence of changes in the seasonal values of various meteorological elements for many parts of the world. I will quote only one example which is more or less typical of all. I take from one of Hildebrandsson's recent papers the curves representing the winter rainfall of Java and

the subsequent summer pressure of Bombay (Fig. 195). The parallelism between the run of the curves is very remarkable, and certainly suggests direct or indirect association between the one element and the other, although they are separated by so long an interval of time.

Many other associations equally striking, but for shorter periods, are given by Mr. R. Mossman in "Symons' Meteorological Magazine," vol. 48, 1913.

There is no objection on philosophical grounds to the existence of a causal connection between one element in one locality and another in a different locality. The sum total of the phenomena of weather must be regarded as represented by the general circulation of the atmosphere, and the differences between one season and another must be represented by some alteration of the general circulation. It is only natural to suppose that an alteration which produces a departure from normal of one kind in one locality will be necessarily associated with a modification of a different kind elsewhere. So that, without being able to describe the precise mechanism by which the changes are carried out, we may expect to find the results of the working of the mechanism in the statistics of meteorological data. Some years ago I drew attention to a remarkable parallel between the seasonal variation in the trade wind at St. Helena and the rainfall in the South of England, and some other noticeable points in connection with the variations of those two elements which might possibly be explained on the theory that the rainfall in the South of England depended upon the general circulation of the air in the northern hemisphere, and therefore upon the arterial flow of air in the south-east trade wind. The paper is printed in "Nature," vol. 73, p. 175.

The result of that note was that an enterprising London newspaper initiated forecasts of rainfall in the south of England directly from the records of wind at St. Helena. They were not altogether successful, but a suggestion by Mr. J. I. Craig, of the Egyptian Meteorological Service, that the Nile flood might be

dependent upon the pressure and wind at St. Helena was more fortunate. A computation of the flood in which the recorded wind at St. Helena forms part. has been continued for some years.[1] The Nile water is certainly more directly connected with the south-east trade than is the rainfall of the south of England. It is indeed not improbable that the rainfall of Abyssinia, which feeds the Blue Nile, is actually derived from the Atlantic Ocean by means of a current of air which comes up from the south-east with the trade-wind, passes over the Gold Coast and along the equator to deposit its water at the sources of the Nile.

COEFFICIENTS OF CORRELATION

In dealing with this subject it becomes a matter of considerable importance to have some means of estimating or comparing the reality of such associations as are represented by the general similitude of the run of two curves representing the sequence of two separate elements. Such a method is afforded by the computation of the coefficient of correlation between elements in the sense introduced into this country by Sir F. Galton, and recently developed by Professor Karl Pearson and others in connection with statistical researches.

The coefficient of correlation is a number which expresses the relationship between the deviations from normal of corresponding values of two elements. If the deviation of the one element is always proportional to the corresponding deviation of the other, which would be the case if the two curves drawn to suitable scales were exactly similar, the coefficient of correlation would be 1; it would be -1 if the one curve were the exact reflection of the other; if, however, the variations were fortuitous and the deviations in no way connected, a correlation coefficient which worked out at zero would express that fact. Hence, an opinion may be formed upon the actuality or otherwise of the relations between the deviations of two elements by examining the magnitude of the correlation coefficient and its probable error. For particulars as to the method of computing the coefficient and the probable

[1] See "Q. J. Roy. Met. Soc.," vol. 36, p. 341, 1910.

error, I may refer to the "Computer's Handbook," of the Meteorological Office. Here I need only say that the correlation coefficient exceeding ·3 is suggestive of a connection between two elements, and one which exceeds ·5 is conclusive, provided in each case that the probable error is not more than one-third of the coefficient.

The method is intended to be applied primarily to the study of the relationship between elements for which large numbers of data are available, because the principles upon which the theory of correlation is based are founded upon the laws of probability applicable to large numbers of observations. The use of the method in the case of meteorological data for a comparatively small number of years is no doubt open to some objection, but it is a very useful way of giving numerical expression to the degree of apparent similarity between curves representing the sequence of numbers. For many years the method has been employed in India as a means of forecasting the general character of the monsoon seasons. The description of the method which has been adopted is contained in various memoirs and publications of the Indian Meteorological Department; the paper by Dr. G. T. Walker on "Correlation in Seasonal Variation of Climate," "Memoirs of the Indian Meteorological Department," Vol. 20, Part 6, 1909, may be specially referred to.

TABLE OF CORRELATION COEFFICIENTS BETWEEN THE MONSOON RAINFALL AND THE FOLLOWING ELEMENTS.

Mauritius pressure, May	−·45
South American pressure, April and May	+·45
Sub-equatorial rainfall, May (Zanzibar and Seychelles)	−·5
Himalayan snowfall, May	−·3
Indian pressure, previous year	+·5
Monsoon rainfall, previous year	−·2

In a "Memorandum on the Abnormal Features of Recent Weather, with a Forecast of the Probable Character of the South-West Monsoon Rains of 1907,[1]" Dr. Walker gives the above-quoted table of correlation coefficients between the mon-

[1] "Memorandum on the Meteorological Conditions, &c., Simla," 1909

soon rainfall and various other meteorological data, defining the correlation coefficient between the elements as "the proportion of the variations of either quantity which are determined by those of the other."

He also gives the following formula for "the most likely rainfall departure corresponding to given values of the six factors in the above table":

$$\{\text{Monsoon rainfall}\} = \cdot 35\,\{\text{S. Amer. press.}\} - \cdot 6\,\{\text{sub-eq. rain}\} \\ + \cdot 1\,\{\text{snowfall}\} + \cdot 55\,\{\text{Ind. press. prev. yr.}\} \\ + \cdot 05\,\{\text{Ind. monsoon prev. yr.}\}.$$

The equation connects the proportional departures from mean values of the quantities within brackets, the proportional departure being the ratio of the actual departure to the mean value of the departure over the series of years. The term involving Mauritius pressure does not appear in the equation.

The discussion of the subject is continued in subsequent memoranda of the Department. It includes an examination of the correlation of sunspots with rainfall, temperature and pressure at 167 stations in all parts the world. See "Memoirs of the Indian Meteorological Department," Vol. 21, Parts 2, 9, 10, 11, 12, and Vol. 23, Part 2.

The relationships of many meteorological elements as well as of seasons and crops have been published in the form of coefficients of correlation. All those that had significance for meteorology and its applications were collected by Dr. E. H. Chapman in 1918 and published by the Meteorological Committee as a continuation of Part V. of the "Computer's Handbook (M.O. 233). From the very numerous collection therein contained we select the following as giving coefficients of ·5 or more :—

Simultaneous pressure and temperature in the upper air at all seasons for all heights from 4,000 to 8,000 metres (W. H. Dines)	·75 to ·92
Rainfall at Havana, May to October, with rainfall in S.W. England in the following January to March (A. Hampton Brown)	— ·54

Nile flood (volume of water passing Aswan, July 1 to October 31) and winter rainfall, May to August, of the same year at Santiago de Chile (R. Mossman) .	— ·62
Rainfall, January to March, at Baltimore, U.S.A., and at San Fernando, Spain, for the same months (Mossman)	— ·57
Barometric gradient at Zikawei (China) in March, and air-temperature in N.E. Japan in July to August (Okada).	·68 to ·78
Air-temperature at San Francisco in July, and air-temperature at Irkutsk in April (Okada) . .	— ·53
Strength of the trade-winds in the North Atlantic, March to August, and the temperature in Holland in the following winter (Gallé)	·76
Pressure, June to August, at St. Helena and Nile flood (Craig)	·61
Sunspots and rainfall at Bathurst, Gambia (Walker).	·51

We add:

Sunspots and water-level at Port Florence, Lake Victoria (Meteorological Glossary) . . .	·8

ANALYSIS IN PERIODIC TERMS

The pursuit of the solution of the problem of the sequence of weather by analysis into periods is by no means finished.

A most fascinating method of approaching the subject is the study of the rings of growth in the sections of trees as worked out by Mr. Ellsworth Huntington, of Yale University, and Mr. H. E. Douglass, Director of the Steward Observatory, Arizona, and described in a book on "Climatic Cycles and Tree-Growth," published by the Carnegie Institution of Washington in 1919. By the measurements of rings in sequoia a record of growth of four trees was made out from 1220 B.C. to 252 B.C. and another, of eleven trees, from 271 B.C. to A.D. 1915; taken together the range is over 3,000 years. From the summary as set out on p. 111 of Douglass's work, we extract the following:—

"(1) The variations in the annual rings of individual trees over considerable areas exhibit such uniformity that the same rings can be identified in nearly every tree, and the dates of their formation established with practical certainty.

"(2) In dry climates the ring-thicknesses are proportional to the rainfall with an accuracy of 70 per cent. in recent years, and

this accuracy presumably extends over centuries. . . . the tree-records therefore give us a reliable indication of climatic cycles and of past climatic conditions. . . .

"(4) Double rings are caused by spring-drought. . . .

"(6) Certain areas of wet-climate trees in Northern Europe give an admirable record of sunspot-numbers, and some American wet-climate trees give a similar record, but with their maxima one to three years in advance of the solar maximum. . . .

"(7) Practically all the groups of trees investigated show the sunspot-cycle or its multiples. . . .

"(9) The tree-curves indicate a complex combination of short periods including a prominent cycle of about two years."

The boldest advocacy for predicting future weather by ascertained periodicities is that of Sir William Beveridge,[1] who has made out a table of wheat prices in Western Europe from 1500 to 1869, adjusted them for secular variation, and ascertained their most persistent periods by harmonic analysis. Selecting the chief periodic terms thus obtained he has combined them to form a synthetic curve for the years 1850 to 1920 and compares the curve thus obtained with the records of rainfall for Europe in the years 1850 to 1921, and finds that it would have been an efficient means of predicting the rainfall if it had been applied. The correlation between the rainfall so computed, and the actual rainfall is about ·4. Considering the severe test to which the method is applied the result is certainly astonishingly large.

The periods which Sir William Beveridge uses for the synthetic curve are as follows: 3·415, 4·415, 5·100, 5·671, 5·960, 8·050, 12·840, 19·900, 35·500, 54·000, 68·000 years.

It is the strongest bid that has been made for long-period forecasting on a scientific analytic-synthetic basis if we disregard the claims of the quasi-astrologers.

As a work of strenuous labour we may compare with it D. Brunt's analysis of Greenwich temperatures for sixty-five

[1] "Weather and Harvest Cycles" ("Economic Journal," vol. 31, 1921, pp. 429—452); "Wheat Prices and Rainfall in Western Europe" ("Journal of the Royal Statistical Society," vol. 85, Part 3, 1922, pp. 412—478).

years into ninety harmonic terms.[1] His summary of results is as follows :—

(1) A large annual variation whose second and third harmonics are also appreciable.

(2) Certain periods such as the five-year period, which appear to exist throughout the interval of 65 years investigated.

(3) Certain periods, such as the 594·5-day period, which exist for a part only of the interval considered, after which they suddenly die away.

(4) Rather doubtful periods such as that of 26·21 months, which an examination of a longer series of records might prove to be illusory.

It ought, however, to be remarked that by these extensions of the period over which the observations range, or the intensive application of a particular form of analysis, we implicitly rely upon an assumption that the effective periodic variations are persistent through the ages, and that only those count whose periodicity is perfect. By confining ourselves to perfect and persistent oscillations we base our work upon a consistent and perpetual periodic cause which impresses itself with more or less effect upon the phenomena which we examine, although it is external thereto; and which can be detected and isolated by sufficient analysis.

We have before us the analogy of the forced vibrations in sound. We know in that case that the forced oscillations, if continued long enough, will dominate the motion of any vibrating body. The natural vibration will ultimately die out, and the cause of the vibrations will be disclosed when we find the forced oscillations to which the motion is due.

It is worth while to consider whether we are really entitled to act upon the analogy as regards the ultimate effect of a continued periodic impulse, and ought not to consider the other possibility, namely, that the system which we are examining has natural periods of its own and the primary effect of any periodic cause is to set the system vibrating in its natural periods; these take

[1] "Q. J. Roy. Met. Soc.," vol. 45, 1919, pp. 323—338.

some considerable time to die out, and are renewed by any fresh impulse of any character whatever. A fresh impulse of an arbitrary character will change the phase of the existing natural vibrations, and for that reason render the resulting variations unsuitable for the application of any rigid system of harmonic analysis.

We ought, in fact, to consider whether the growth of trees, the successive crops of wheat, and so on, when subjected to any catastrophic changes have any natural resilience of their own. If there is any such natural resilience there would be corresponding natural periods of oscillation. We certainly do not know what those natural periods are, but it is not quite proper to ignore them; because, if the phenomena have no such resilience they stand in a class apart from most things in heaven and earth.

Consider, for example, the growth of trees. Suppose that its normality is disturbed by a catastrophic year of drought. If the rainfall next year resumes its normality will the tree also do the like? From what is known about trees one would be disposed to say no. A year of drought may be followed by a year of exceptional fruiting which is at least a difference from normal.

The same may perhaps be said about wheat. And none would be found to deny that the general circulation of the atmosphere would present some features of resilience if once disturbed. Perhaps an experimental test might be tried with wheat by growing it normally for some years under steady conditions as in Egypt, transporting the seed to Norfolk or Rothamsted; growing a crop there and returning its seed to Egypt for growth under normal conditions until all effects of the transplantation had been lost. If by any chance it should happen to take eleven years to recover its tone we should have learned something about periodicity in wheat which would enlighten the whole subject.

And this brings us into contact with some speculations of Professor H. H. Turner,[1] who finds that the fluctuations of meteorological records are more rational if they are grouped into

[1] "Q. J. Roy. Met. Soc.," vol. 41, pp. 315—336, 1915; vol. 42, pp. 163—173, 1916; vol. 43, pp. 43—60, 1917.

separate "chapters" than regarded as a continuous story. What begins or ends a chapter we do not know. We should have to note the events that are catastrophic for the various phenomena. We have suggested a very dry year for trees, and a transplantation for wheat: perhaps a violent volcanic eruption might, by its dust, produce dislocation of the general circulation of the atmosphere (see Humphreys, "Physics of the Air," Part IV., Chapter V.). As a castastrophic event on the sun we may perhaps think of its contact with a swarm of meteors, and I have some recollection of Sir Arthur Schuster having associated the thirty-three-year period of the Leonid swarm with three eleven-year periods of sunspots.[1] But in any case we should be further on our road to long-period forecasting if we could assume that the phenomena had natural periods and responded to external influences on the analogy of resonance rather than that of forced vibration.

[1] "Proc. Roy. Soc. A.," vol. 85, p. 53. 1911.

CHAPTER XXIV

WEATHER PREDICTION BY NUMERICAL PROCESS

To the various suggestions that have been made for new methods of forecasting in extension of, or in substitution for, the empirical method of diagnosing from experience the behaviour of cyclones and anticyclones and other groupings of isobars on maps, we have now to add a new one described by Mr. Lewis F. Richardson in a book entitled "Weather Prediction by Numerical Process," which was published by the Cambridge University Press in 1922. It is novel in the sense that its plan of action is to carry into direct effect what has always been regarded as a necessary step in the emancipation of meteorology as applied to forecasting from the empirical process of the weather map; that is, to employ for the interpretation of the present and the prognosis of the future a sufficient knowledge of the application of the principles of dynamics and physics to the known conditions of the atmosphere.

His position is that the changes of the meteorological elements with time can be represented by certain general equations for the motion of air on a revolving spheroid which, with other well-recognised equations such as the equation of continuity of mass and the characteristic equation of a mixture of air and water are technically sufficient for the calculation of the future values of the elements if the data for all the quantities which occur in the dynamical equations are known. About the method of weather charts he remarks in the preface of his book :—

"The process of forecasting, which has been carried on in London for many years, may be typified by one of its latest developments, namely, Col. E. Gold's 'Index of Weather Maps.' It would be difficult to imagine anything more immediately practical. The observing stations telegraph the elements of present weather. At the head office these particulars are set in

their places upon a large-scale map. The index then enables the forecaster to find a number of previous maps which resemble the present one. The forecast is based on the supposition that what the atmosphere did then, it will do again now. There is no troublesome calculation, with its possibilities of theoretical or arithmetical error. The past history of the atmosphere is used, so to speak, as a full-scale working model of its present self.[1]

"But—one may reflect—the 'Nautical Almanac,' that marvel of accurate forecasting, is not based on the principle that astronomical history repeats itself in the aggregate. It would be safe to say that a particular disposition of stars, planets and satellites never occurs twice. Why then should we expect a present weather map to be exactly represented in a catalogue of past weather? Obviously the approximate repetition does not hold good for many days at a time, for at present three days ahead is about the limit for forecasts in the British Isles. This alone is sufficient reason for presenting, in this book, a scheme of weather prediction, which resembles the process by which the 'Nautical Almanac' is produced, in so far as it is founded upon the differential equations, and not upon the partial recurrence of phenomena in their *ensemble*."

The equations are differential equations of a very complicated character. The three fundamental dynamical equations each contain nine terms, some of them in themselves composite. No solution in general terms which would give the elements themselves in terms of the time is possible. The problem, which Mr. Richardson has set himself, is to solve them by the process of

[1] When reading the proof-sheets of this chapter Mr. Bilham demurred to Mr. Richardson's description of the method of forecasting by reference to past history as suggesting a merely mechanical process. The question is in reality one of the niceties of language. I quote a parallel from an entirely different subject.

"Does History repeat itself? The precisian denies the possibility. 'That is the one thing,' as Lord Bryce once said, 'that history never does.' But in making that observation Lord Bryce had political history uppermost in his mind and the dogmatic denial might have been modified in relation to social and economic history. The operation of economic laws is constant: certain causes produce certain results. The resulting phenomena are of course modified by circumstances, but there is sufficient constancy to justify prediction" ("Fortnightly Review," March, 1923, p. 503. J. A. R. Marriott on "Poverty, Pauperism and Public Assistance.")

finite differences, that is to say, by having a sufficient number of the changes of the elements from place to place on a map, he can get an approximate estimate of the next step in the process of time. His plan is to divide the whole area (ultimately of the globe) as a chequer board of red and white squares each 200 kilometres from south to north and something like the same from east to west. Pressure is to be observed at the centre of each red chequer and velocity at each white, for each of five layers which make up the atmosphere above the chequers; and from the data, with a large amount of knowledge of the radiation, the transference of water, heat and momentum from the ground and other external effects, the material can be applied to the computation. The present distribution of stations is not ideal for the supply of the material; it has grown up on other grounds. But Mr. Richardson has used it for the computation of the changes during six hours for two points in 1910, May 20, 7 h. G.M.T. He claims that "the results form a fairly correct deduction from the somewhat unnatural initial distribution."

It took him the best part of six weeks (in a rest billet in France) to make the forms which occupy twenty-three quarto pages, and the computation of the changes at two points of the map. He estimates that if the time-step were three hours, thirty-two individuals would just be able to compute two points so as to keep pace with the weather. That amount of labour is not to be wondered at when it is known that a list of different quantities which enter into the equations runs to ninety-two; the demand for symbols is so great that the Coptic alphabet is drawn in to supply some of them.

The process as thus described in its present form is not likely to be adopted by official forecasters, and we cannot offer it to the reader as Richardson's "Ready Reckoner" for forecasts. It has been playfully said that on this method it would take a year to forecast to-morrow's weather from to-day. But the effort to bring the processes of weather under numerical computation is by no means wasted. In the course of mapping out the computation, as in no other way, the dynamics and physics of many of the

processes of weather are made clear, and a very large amount of information about the atmosphere, difficult to acquire, is contained in the book.

The introduction of physical and mechanical computation into the study of the atmosphere remains an urgent requirement, and perhaps the best course is to devise some form of grouping of the facts into systems which will economise the labour of computation.

If visitors from Mars, unfamiliar with engines and, at the same time, familiar with Cartesian co-ordinates, happened upon the engine room of some big ship, they might endeavour to unravel the mystery of that great development of power by dividing the space occupied by the machinery into points arranged according to co-ordinate axes. If they did so it would take a vast amount of computation to arrive at an idea of the constituent parts of the machinery which would certainly be disclosed to them in time if they examined enough points. In the end they might, of course, know more about it than the hasty visitor who recognised a turbine or a cylinder or a shaft: but as working knowledge what they knew would be less useful.

It is possible to carry the process of minute analysis too far. There is a story of a conversation between Maxwell and Tyndall which may or may not be in print. Talking of the ultimate molecular constitution of matter Tyndall pointed out to Maxwell how curious it was that the pulling force depended on the mutual attraction of separate molecules, and said that the traces by which a horse drew a cart were not really continuous, but were held together by attraction at a distance. "Yes," said Maxwell, "but when you are in the cart it is very comforting to know that the traces are there." In like manner, the grouping of the phenomena of the atmosphere into entities, which are sufficiently persistent to be dealt with as working units in selected situations and which can be recognised in maps, remains as a possible alternative to a generalised system which is equally applicable to every meteorological situation and at all times. The application of Mr. Richardson's method to such selected types should prove very illuminating.

F.W.

CHAPTER XXV

THE PRACTICAL UTILITY OF WEATHER FORECASTS

In dealing with this part of the subject I wish to speak of forecasts as now issued, either directly by telegraph or by publication in the newspapers.

The summaries of the forecast checking, as given by the Meteorological Office in the annual reports presented to Parliament, showed that according to the accepted method of checking, 56 per cent. of the forecasts are completely successful, and an additional 31 per cent. are more nearly right than wrong, so that 87 per cent. give a fairly accurate indication of the weather for the period to which the forecasts refer.

Before going further it may be of interest to explain a little more in detail what this method of checking is. The forecaster is supposed to provide in his forecast an indication of six separate aspects of the weather to be expected in the district for which the forecast is drawn :—(1) the direction of the wind; (2) its force; (3) the state of the sky as regards cloud; (4) the precipitation of rain, snow or hail; (5) the temperature; and (6) such occurrences as thunderstorms, fog or night frost.

It must be remembered that for telegraphic purposes the description of the weather has to be confined as nearly as may be to twelve words. This in itself is a limitation which has obvious advantages. On the other hand it is no easy task to describe the weather of the past twenty-four hours in twelve or fifteen words. To do so requires a good deal of convention. Convention is equally necessary in writing a forecast: for example, "strong to moderate," referring to the wind force, or "fair to fine," referring to the weather, must be understood to describe the transition from the one state to the

other in the order named during the period of the forecast. Some acquaintance with the telegraphic language used for forecasts is therefore a necessary preliminary for comprehending the situations which they are intended to describe.

With this understanding the forecast-checker compares the statement of the weather given in each of the district forecasts with the weather recorded at the telegraphic stations which report wind, weather, temperature, etc., and at the climatological stations of the Weekly Weather Report which give temperature, sunshine, rainfall, and some notes of the weather. If all the statements in the forecast are verified, it gets an "A," if more than half a "B," less than half a "C," all wrong or not more than one right a "D"; the A's and B's are the complete and partial successes, the C's and D's partial and total failures.

This mode of procedure disposes to a certain extent of a criticism that is sometimes made to the effect that any forecast taken at random has equal chances of being justified by subsequent weather, and that only the successes over 50 per cent. are properly to be attributed to correct anticipation. This is only true in so far as all the phenomena can be regarded as hanging together, and the whole set of items resolvable into two classes as "fine" or "wet." There is a certain amount of association between the different items, but it is not nearly so complete as the inexperienced may think. To write fine weather as a necessary accompaniment of an easterly wind in this country, for example, would lead a forecaster to some modest successes, but also to some harrowing failures.

In countries where the seasonal climate is settled, and seventy-five days out of a hundred in the summer are fine, the forecaster may still be judged by his successes and failures as regards winds and temperatures, while the forecast as regards rain may be taken for granted.

But clearly by using only what the forecaster has announced

as the basis of checking, some advantage is given. By judicious omission or by vague wording a forecast may be given which "keeps the word of promise to the ear, but breaks it to the hope." A disappointed reader may acknowledge that the forecast is true, but complain that it is not the whole truth, and that the part omitted was the most telling part. Instances could be quoted in which the forecasts have been verbally verified, when the general inference upon which the forecasts were based was clearly wrong. But there are retributions even here; the principle of the general inference is sometimes quite correct, and the caprices of the weather make the application something quite different from what might fairly have been expected.

Within its limitations the checking of the forecasts is very rigidly carried out, and, generally speaking, if an inexperienced person takes up the duty of checking, the percentage of successes comes out higher than that given by the mechanical system to which experience inevitably leads.

A more serviceable method of checking the forecast would be to prepare for each district a brief statement of the weather for the forecast period, and then mark the items which the forecaster had correctly anticipated. One could then give to the events the proportion which they present to those who experience the weather. For example, a sudden thaw replacing a period of frost would not be covered by the general term "warmer," and twenty-four hours of continuous heavy rainfall would not be regarded as adequately indicated by "some rain." The difficulty in the way of introducing this method of forecast-checking is the labour of preparing an adequate summary of the weather for the several districts from the observations at fixed hours, with the knowledge that the description requires skill and judgment and, when it has been prepared and the forecasts once checked, it has no further utility. It is not, as a matter of fact, called for to meet the current requirements of any of the official reports.

Let us take then the statement of the success or failure of

the forecasts at the figure given in the official summaries, and consider their utility on that basis. Unfortunately we cannot suppose that the impression produced upon the casual recipient of the forecasts is expressed by the percentage of successes. It would be so if everybody received the forecasts every day and used them accordingly, but that is generally not the case. The forecasts published in the morning papers are put before the reader say between 8 a.m. and 9 a.m., later, perhaps, in some country districts, and by that time eight or nine hours, and those the best from the forecaster's point of view, have already elapsed. Consequently the forecasts have already lost a good deal of their vitality, and the interest of the reader is likely to degenerate into curiosity as to whether the forecast has been fulfilled or not. It is, in fact, not unusual to find that a reader of the paper supposes a forecast to be a description of the weather which he is experiencing at the time he reads it.

The forecasts in the "evening" papers are on a somewhat better footing from that point of view. They are issued now at 10 a.m., and refer to the period from noon to noon. They may be in the hands of the public by noon or 1 p.m. But the period which most persons are interested in as regards weather is the daylight period, and the period of the morning forecast includes the coming night, so that the period of interest is separated into two detached portions by an interval with which the ordinary observer has little concern. Things would be on a better footing in this respect if the morning forecasts could be issued for the period from the midnight following the issue to the next midnight, and the evening forecasts for the period 6 a.m. to 6 a.m. of the following days.

This, however, is for the future. We may suppose that for the great majority the experience of the forecasts is that which is derived from an inspection, more or less regular, of the newspaper reports. The inspection will be cursory if the reader has no particular interest in the day's weather, and interested upon the few occasions upon which anything of

importance turns on it. For many days in the year the weather, good or bad, is taken by many people as it comes, with only the amount of grumbling that the art of conversation demands, and it is only on occasions of some exceptional importance that they indulge in the eighteen-penny luxury of a forecast by telegram. But it is upon the results of these, not upon the percentage of large numbers, that the individual opinion of the utility of forecasts is likely to be based. In these circumstances it is not possible to make the best use of a system that can claim 60 per cent. of complete successes or 90 per cent. of partial successes.

Anyone receiving a telegraphic forecast for the first time hardly knows what to do with it. He looks at the sky and ransacks his own experience; if his habitual prognostics support the forecast he will act upon it; if they are in conflict with it he can hardly trust himself to the inferences drawn from premises unknown to him by persons who do not live out of doors or otherwise share his experience. In the end he is almost sure to be guided by his own experience and then indulge in a judgment *ex post facto* upon his wisdom in having so determined.

The fact is that the effective use of telegraphic forecasts requires practice, and it also requires co-ordination with the prognostics, general or local, with which the user is familiar. Supposing that we could re-arrange the practice of forecasting so as to give in the evening the weather anticipated for the period 6 a.m. next morning to 6 a.m. on the following morning, and in the morning the weather from the approaching midnight to midnight next evening or even from 6 p.m. to 6 p.m.; and if the percentage of accuracy could be kept up to its present figure, there is no doubt that the recipient who always acted upon the forecasts would find them on the average of effective utility, and the utility could be very greatly enhanced by the consideration day by day by some person of special knowledge on the spot of the relation of the forecasts to actuality, the reasons for success and

failure, and the preliminary signs of the commencement and sequence of the changes anticipated. This development requires a local knowledge of the principles of forecasting by means of weather charts which might form part of a rural education. A well-informed correspondent in possession of the general inferences could probably give a local forecast that would be better applicable to the particular district than the general official forecast. One of the difficulties about realising such a project lies in the inherent tendency of all persons to adopt the role of specially gifted experts. Weather forecasting ought not to be a matter of occult reasoning, of secrets and special genius, and it will never be satisfactorily applied so long as there is an element of secrecy or even of *expertise* in any sense but the common sense of the possession of properly trained intelligence. The premises must be common property and the inferences must be capable of being expressed in language comprehended by persons of ordinary education, and it is therefore of importance that the ordinary education should include suitable knowledge of the principles of meteorology to enable the ordinary and inexpert person to understand and put in practice the necessary inferences for himself.

Until such a development is possible we cannot be said to have a *system* of forecasting, and a judgment as to the utility of our forecast practice gives no adequate information upon the progress of the subject from the scientific point of view.

After what I have said it is not surprising that the reports which we get about the application of forecasts deal more with their accuracy than with their utility. Correspondents who receive the harvest forecast by telegram, and who are always invited to supply notes of the weather which enable us to check the accuracy, frequently report that the forecasts were remarkably accurate, but they seldom go so far as to say that they were acted upon with advantage. Occasionally I have learned that persons acting upon the forecasts have saved themselves from difficulties which were otherwise unforeseen.

In recent years the Office has endeavoured to meet the special requirements of farmers by supplying notices of the prospect of settled weather that might be utilised for getting in hay or corn crops. Very enthusiastic acknowledgment of the utility of these forecasts has been expressed in terms of hundreds of pounds by an agricultural firm in Cornwall.

In other directions the examination of the practical utility of forecasts has given less satisfactory results. In 1893, and again in 1894, the Board of Agriculture made a trial of the issue of forecasts by telegraph during the harvest season to post-offices in selected counties, of which there were six in 1894. After the second year the experiment was discontinued. The reasons for its discontinuance are not stated in the Meteorological Council's Report, but a memorandum by Dr. H. N. Dickson on the application of the forecasts to four centres in connection with the University Extension College at Reading is printed. In effect it expresses the view that even if the forecasts were accurate from the point of view of the meteorologist, the districts for which they were made included local variations of weather which made them inadequate for the practical requirements of the farmer. It may be gathered that that view was adopted by the Board of Agriculture, and an inference which might fairly be drawn is that a sub-division of districts should be made and separate forecasts issued for these sub-divisions. Such a suggestion could not be carried out in practice; that is to say, it is not practicable for a single individual to bear in mind and act upon the meteorological peculiarity of every parish in the three kingdoms. Yet it is undesirable that the matter should be left in its present state. Dr. Dickson concluded his memorandum by suggesting that the working out of rules for the application of a general forecast to individual localities would be a legitimate undertaking for the agricultural department of a college, and that the value of the forecasts would be greatly increased if the farmers received sufficient instruction in meteorology to enable them to understand the general nature of the changes predicted.

In these respects the question remains almost in the same position as it was in 1894. In recent years however, there has been a noteworthy movement in the direction of introducing the study of the weather as a form of nature-study for country schools and of using the Daily Weather Report in illustration of the subject, so that a welcome beginning has already been made.

It is often stated that local experience can do with less expense and greater certainty all that students of synoptic weather charts are able to do. So far as I know, in spite of the urgent necessity for some guidance in the matter, the local weather prophet is not in practice more honoured than the central organisation, and it seems hardly credible that an effective system could have been allowed to fall into neglect for the mere want of writing down and distributing a statement of the probable course of events. The attitude of the farmer or of anybody else, to any new departure of this kind is not likely to be unjustly favourable in the first instance. It was very appositely described recently in a newspaper which said that a farmer would never admit that the forecasts were of any value, but if his neighbour was receiving a daily forecast by telegram, as a matter of curiosity he always took care to find out what it said.

For the dwellers in cities life is so organised that the variations of weather seem to be of little importance, and a forecast tends to be a matter of curiosity verging on the important as the week draws to its end. The means of transport on land and sea have been so greatly improved and developed as to give the impression of being independent of the weather. This attitude, which is justifiable with certain limitations, sometimes finds expression in various ways. A post-office official once told me that a knowledge of to-morrow's weather would be of no utility to the rural postal service, because His Majesty's mails had to be carried whatever the weather might be. The dwellers in cities often forget the conditions under which the supply of the daily necessaries of life,

as milk, meat, or vegetables, is carried on, and the extent to which the proper ordering of the supply is contingent upon the weather. Our feeling of independence of the weather is sometimes sadly shocked by the paralysing influence of a snowstorm or a fog, and we are forcibly reminded that it is not only the health-resort that is interested in to-morrow's weather.

It is in connection with agriculture and the supply of the necessaries of life that the work of forecasting should find its application. For the excursionist and the holiday-maker the uncertainty of to-morrow is really part of the interest. So much is the holiday-maker disposed to look upon the brighter side of things that it is not at all improbable that, if we could describe to-morrow's weather exactly, with all its dripping accuracy, some protests would be raised against the publication of the information as interfering with business. But with the agricultural world it is different. They are not by nature so optimistic. It would be a matter of great interest to know the actual yield of farm produce each year estimated as a percentage of the maximum possible under the most favourable circumstances of weather, and by how much a promising result is spoiled by bad weather. The destruction of lambs by heavy snowstorms, of fruit and potatoes by late frosts, the shortage of hay or roots for want of water, and the loss of crops by inclement harvest weather all put together would total up to a large percentage and a vast sum of money. To these must be added the loss or depreciation of live stock or perishable goods in consequence of rough weather, or delays in transit, or the overstocking of the market in bad keeping weather. With a lifelong experience of a heavy percentage of inevitable losses it is little wonder that the farmer should take a philosophic view of the situation. If he is to lose something like 40 per cent. it seems hardly worth while to trouble about a margin of 1 or 2 per cent. But the difference might easily reach a figure that would convert a loss on the year into a profit, and whatever is gained by improving our knowledge of

the weather is so much to the good, even though it be not the whole, so that there is certainly a golden opportunity for successful forecasts of weather.

Since their introduction sixty years ago the use of synoptic charts has enabled us to make certain definite advances, and the success which has been achieved is sufficient to encourage us to pursue the researches further. It may be that in the end the caprices of weather will after all disappoint us and to-morrow's weather will never be forecasted with sufficient accuracy for all practical purposes. Even in that case the effort will not have been valueless. It is quite possible that the progress of research, guided primarily by the wish to improve the daily forecast, will lead to the recognition of, or find material for, the development of laws of a more general character that will enable us to anticipate the weather for the season or the month. It is only by close practical study that such an object can be achieved.

CHAPTER XXVI

THE FUTURE OF FORECASTING

THE weather of the year 1921 was remarkable for its extraordinary drought, abundant sunshine, astonishing clearness of the air, an inordinate prevalence of fog, some violent gales, and a sudden plunge from the heat of a summer abnormally prolonged till the end of October, to the cold of a premature winter with ice on the Serpentine early in November. Trees and shrubs were tempted into a new array of flowers and leafage when they ought to have been subsiding into their winter's sleep. Strawberries went so far as to yield a second crop. Even the birds were puzzled. Not less so the people of the south and east of England who had some anxiety as to where they were to get water, and wondered what these remarkable changes of season meant, and still more what they might portend.

For there is an ineradicable tendency to regard these curious happenings not so much as evidences of the past, which, indeed, they are, but as nature's method of divulging the future. Perhaps they might be that if our knowledge of the air and the earth were as ample and sufficient for the purpose as our knowledge of the motions of the heavenly bodies that are so much further away from us. To the Babylonians those movements were as perplexing as the sequence of our weather is to us, but succeeding generations have expressed their motions in terms which are applicable to the future as to the past.

Shall we ever know enough about these things to predict the course of coming weather in anything like the way in which our astronomers predict eclipses, or the position of the planets in the sky? Are we making any real progress towards that desirable state of knowledge?

There has been no such keen interest in the general questions of the weather and its future as there was in 1921, since the middle

of last century when the introduction of the electric telegraph first made it possible to get together morning by morning a map of the weather over the whole of North-Western Europe. Those who have never seen a map grow out of its constituent figures have no idea of the fascination which it has. Those who studied the maps soon detected the existence of cyclones, regions of low barometer, wind and rain, far less violent, yet more or less similar in form and character to the tropical revolving storms and hurricanes which had already been a subject of much curiosity and study, and of anticyclones which are just the opposite, regions of high barometer, calms or light airs and fine weather. And the maps confirmed the idea that the cyclones, with their violent weather, and the anticyclones, from which violence was conspicuously absent, travelled across the map, and could be seen to be approaching regions in which their influence had not yet been felt.

The invention of the Weather Map in the sixties excited a fine enthusiasm for meteorology, the science which includes the study of weather maps with some other things, and it seemed to promise a speedy solution of the problems of predicting to-morrow's weather. The enthusiasm caught the newspapers as well as the meteorologists. It began with the *Daily News*, but later it was most cordially taken up by *The Times* and the *New York Herald*. So much so that arrangements were made and carried out for notifying the departure of cyclones from America to be anticipated four days ahead in Britain or France.

After sixty years of experience the problem of to-morrow's weather is not completely solved, and at times the enthusiasm of the sixties has fallen to a very low level among the scientific. The idea of forecasting the arrival of cyclones on our own coasts from their departure from the United States was based on partial knowledge and was dispelled by the study of a series of daily maps of the Atlantic for thirteen months (1882—1883), compiled in the Meteorological Office for the study of the life-history of the cyclones in their passage over the ocean. So far they have only shown that that life-history is complicated beyond description.

Yet the practice of forecasting by means of maps has been adopted by all the official meteorological establishments of the world; it still remains the accepted method of foretelling the weather of to-morrow, and is likely to continue so. A good deal of progress has been made. Prolonged experience has made it clear that the behaviour of cyclones and anticyclones and the variants of those conditions have habits, if not laws; the accumulated knowledge of the relations of our cyclones and anticyclones to their environment has enabled the Meteorological Office not only to forecast to-morrow's weather with substantial accuracy, but also to deal in general terms with a further outlook over the weather of the next few days, and on one occasion recently to intimate successfully the persistence of fine weather for ten days on end.

But we cannot expect that looking at maps alone will ever give us a complete solution of the problem, without effective comprehension of the complicated processes that are implied in the word "weather." Imagine a person with no previous knowledge of chess just watching a chessboard where a game is being played. There are a large number of pieces, some red, some white—call them warm air and cold air, if you will—which are on the move. By observation alone let him try to make out the future course of the game and predict its conclusion. By careful attention he would make out something about the moves of the pieces and from time to time would notice that some of them vanish, and their places are taken by opponents, or that they move out of the way when an attack is impending. No amount of watching would enable him to predict the course of the game unless he could get at the minds of the opposing players, who make the moves.

Scarcely otherwise is the watching of cyclones and anticyclones and their attendant air currents on maps. Their moves, like those of the chessmen, can be reduced to some sort of rule, if not of law. Sometimes they disappear and sometimes seem deliberately to avoid that fate. But the course of the game between the opposing warm air and cold air can only be anticipated when

the minds of the players as well as the motions of the pieces can be read. In the air-game for the players we have the environment of the pieces which we see on the map, and the environment extends throughout the whole atmosphere: the mind of the environment is formed by the laws of dynamics and physics acting through the supply and loss of heat.

There are two ways of bringing into play our knowledge of the physical laws of the environment. One is to note the conditions of the weather in much more elaborate detail than the usual maps, in order that we may trace the physical consequences of what is happening. This plan has been followed in Norway with remarkable success in predicting the occurrence and duration of rain for haymakers, and winds for fisherfolk. In England a learned book on somewhat similar lines has been published by the Cambridge University Press. In Sweden inspiration has been sought in the changes in the barometer readings in a period of six hours. In Germany, also, the same method has been used, and in France it is reinforced by a minute study of the clouds. The other plan is to bring our knowledge of the physical processes of the atmosphere to bear in the form of new principles or laws suitable for the special circumstances of the atmosphere. That also is being tried; it is interesting enough for schools and colleges; but is not yet at the service of haymakers or fisherfolk. The life-history of our weather is extraordinarily involved, but until we know it we are confined to watching the pieces on the chess-board and we are not satisfied.

It is a wide and tantalising study. The same kind of general conditions which made our hot summer (while the East was warm), prolonged until the East was cold, gave us a bitter November.

But, after all, this following of the weather-game from day to day is only part of the matter; what about the weather for weeks ahead or the general character of the seasons? Are we still to be content with what the "hips and haws" have to say, or with the "goose before Christmas" and the "duck after" as the best that science can tell us about the course of the weather?

Some things have been done, and more claimed. Some people think the general character of the weather is regularly periodic according to some period in the behaviour of the heavenly bodies or of sunspots, or of more mundane events. There are people who make a curve of the weather in advance. How they do it is not always disclosed, still less understood, and for some reason or other methods that find acceptance require to be "patent" to the intelligence and not merely to the inventor. The writer once neglected an opportunity of buying the copyright of a method of forecasting the weather like an almanac. Somehow, "copyright" seemed not appropriate to this kind of literature. When the secret of future weather is at long last obtained it is as safe as any forecasting to predict that copyright will be the last thing that the author will worry about. The more likely difficulty will be to find a publisher to take it as a gift. The only case of regular practice of anticipating the seasons that we are familiar with is the forecasting of the Indian monsoon by the Meteorological Office at Simla on the basis of correlation between the rainfall of the monsoon and the previous meteorological conditions of various parts of the world, including such distant regions as South America.

The uncomfortable feature of such applications of statistical methods is that, from the nature of the case, they are conclusions from observations extending over many years, and at least as many years are wanted for the effective confirmation of the results, while individual years may show some serious misfits. It is small consolation to be starved as an occasional exception to a rule which promised plenty.

Meteorologists are gradually feeling their way to some generalisations. The Weather Bureau of the United States was accustomed for years before the war to use a daily map of the Northern Hemisphere as a guide to the general course of events. In Australia it is from the warm north as a rule that rainfall comes; in Europe it is now regarded by a new school of meteorologists at Bergen as part of the play between the warm air of the south and the cold air of the north. But, whatever the details may be they are certainly all part of that general circulation of the atmosphere

which has been going on from the time the atmosphere began, and will continue till the finish.

What is that circulation? Do we know it? Can we describe it? Well, no, we do not know it, and we cannot describe it. We know now that it is not the surface alone that counts. The pieces that are removed from the meteorological chess-board of the surface do not cease to operate when they are "taken." With the observations of the upper air which have been made during the last twenty-five years, and with the results of polar exploration, we are much nearer to a description of the circulation of the atmosphere than our predecessors were twenty-five years ago. And what is obvious is that we must not only have the pile of observations that tell us what is what at any particular moment, but we must also find the skill to compile and co-ordinate the facts in some general description which gives the effective results and disregards the unimportant details. To do that we must not only have details, but enough of them to find out which are important and which not. "Points" are, for example, small details in a railway track; but they have peculiar importance which larger features, such as curves, or inclines, or bridges, or level-crossings do not possess.

As time goes on we get nearer to the knowledge which we desire, and gradually we shall come to the knowledge of what the circulation really is and with what laws our own local conditions fit into it. The secrets of the sequence of weather will be disclosed, and when that happens the "copyright" will belong partly to the folk who invented the instruments, beginning with Torricelli, the pupil of Galileo, who invented the barometer, partly to the enthusiasts who developed the use of weather-maps, and partly to the patient contributors who looked ahead of the situation of their day towards the underlying laws that direct the moves of the pieces in the air-game.

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WHICH ARE REPRODUCED IN THE ILLUSTRATIONS

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